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Abstract

The Ruby Mountains-East Humboldt Range, one of the interior mountain groups of the Basin and Range Province, lies about midway between the Wasatch Mountains and the Sierra Nevada. After Blackwelder's description in his review of glaciation in the western mountains, Sharp mapped and named the deposits of the Lamoille and Angel Lake glaciations and correlated them with early and late Wisconsin deposits of the Great Lakes area. The refinement of relative dating (RD) methods, the availability of air photos and modem topographic maps, and new road cuts have aided the restudy of these alpine glacial deposits and the basis for their correlation. Lamoille moraines are smooth ridges and show little detail of constructional topography. Valleys glaciated only by Lamoille ice still show the characteristics of a glaciated trough, but they have been greatly modified by weathering and erosion. Granite boulders on Lamoille moraines are pitted, and pegmatites have grotesque shapes with 30-cm-deep pits. Cuts through Lamoille end moraines (and alluvial talus cones) expose a thick soil profile with a well-developed blocky structure in a reddish brown argillic B horizon. Subsurface granitic boulders in the B horizon of Lamoille tills show much greater weathering than do those in Angel Lake tills. In contrast, Angel Lake moraines are irregular and rugged, contain closed depressions, and have been little altered since deposition. Surfaces scoured by Angel Lake ice are fresh and unweathered. Granites of Angel Lake moraines have weathered surfaces but show little pitting; pegmatites have pits up to 10 cm deep. The thin soil profiles on Angel Lake tills and alluvial talus cones display brown colors, minor clay accumulation, and no B-horizon structure. These weathering and morphological differences suggest that the Lamoille deposits have been exposed to weathering and erosion for a period of time as much as an order of magnitude longer than the Angel Lake deposits. Thus only the Angel Lake is Wisconsinan in age, and the Lamoille drift is more reasonably correlated with the Illinoian Stage of the Great Lakes region.

Introduction

The identification and correlation of sequences of glacial deposits in separated mountainous regions have been based primarily on such characteristics as the relative freshness of form of depositional features, the degree of weathering displayed by exposed boulders, and the extent of postglacial modification of landforms by fluvial and other geomorphic processes (Blackwelder, 1931; Sharp, 1938). Fossils are rare in alpine glacial sediments, material suitable for radiocarbon dating is not often encountered, and exposures of stratigraphic sequences are uncommon. In recent years, more quantitative techniques have been employed in an effort to distinguish better the deposits of one glaciation from those of another (Birkeland, 1964, 1974; Mahaney, 1978; Burke and Birkeland, 1979). Among the more useful have been (1) thickness of weathering rinds on fine-grained rocks, (2) degree of surface weathering of exposed boulders and of those buried in the solum, (3) depth and degree of soil-profile development, and (4) degree of postdepositional modification by erosion and deposition.

Except for Blackwelder's (193 1) Sierra Nevada-Basin Ranges paper and the classic work of Sharp (1938) on the Ruby Mountains-East Humboldt Range few studies of glacial deposits in the interior mountains of the Great Basin have been published. Marginal to the Great Basin, many reports have appeared on the Sierra Nevada (e.g., Blackwelder, 1931; Sharp, 1960, 1972; Birman, 1964; Birkeland, 1964; Burke and Birkeland, 1979) and on the Wasatch Mountains (Blackwelder, 193 1; Richmond, 1964; Madsen and Curry, 1979). The Ruby Mountains-East Humboldt Range east of Elko, Nevada (**Fig. 1**), is a fault block that lies midway between the Wasatch Mountains and the Sierra Nevada and is the most extensively glaciated range in the Great Basin. The range is composed of metamorphic rocks of early Paleozoic age (Howard, 1971; Howard et al., 1979), mainly quartzites, talc-silicates, and marbles, that have been intruded by granite and granite pegmatite. The highest peaks in the range exceed 3350 m in altitude, and most of the ridges stand higher than 3200 m. The average altitude of the cirque floors rises from 2710 m at the north part of the East Humboldt Range to 2860 m about 100 km to the southwest in the Ruby Mountains. Individual cirque floors range from 2810 to 3060 m in the vicinity of Lamoille and adjacent valleys, the principal area examined in this study.

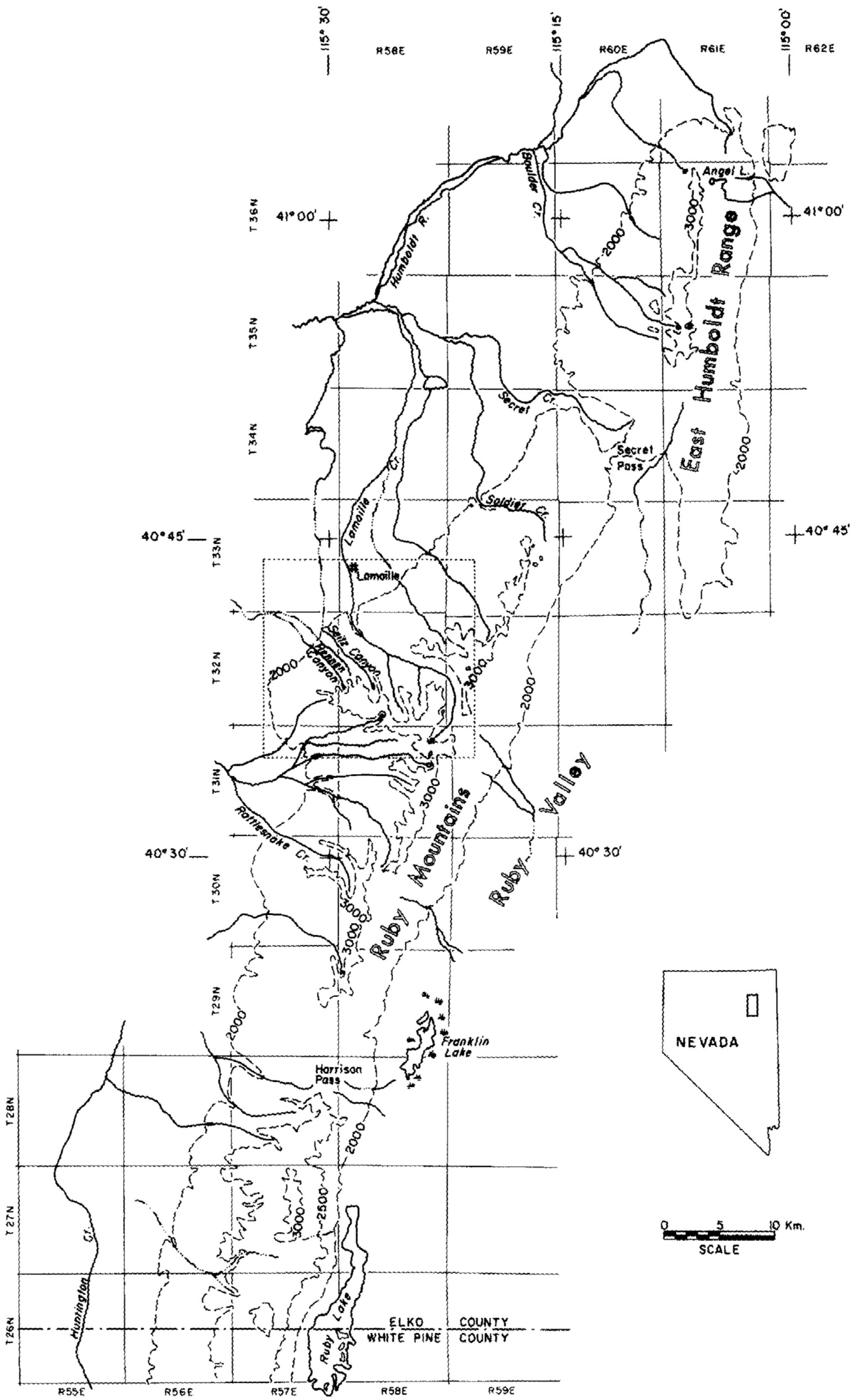

Fig. 1. Index map of East Humboldt Range and north part of the Ruby Mountains showing 1000-m contours and major drainage lines. Outline shows area of Figure 2. From U.S. Geological Survey Elko and Wells quadrangles, scale 1:250,000.

Blackwelder (193 1) and Sharp (1938) recognized and described the deposits of two glaciations in the Ruby Mountains. They correlated the older, the Lamoille, and the younger, the Angel Lake, with the Tahoe and Tioga moraines, respectively, of the Sierra Nevada and with the Bull Lake and Pinedale glaciations of the Rocky Mountains, which Blackwelder (193 1, p. 918) tentatively correlated with Iowan and Wisconsin glaciations of the midcontinent region. Sharp (1938, p. 300) recognized that the Lamoille deposits were considerably more weathered and eroded than those of Angel Lake age, but did not believe the difference was great enough to represent two separate glacial stages. He referred them to early and late Wisconsin glaciations, respectively. The criteria developed in the Sierra Nevada to distinguish glacial deposits of different ages (Blackwelder, 1931, pp. 870- 880) were applied by Sharp (1938, pp. 300- 304) in the Ruby Mountains-East Humboldt Range to verify the extent of each of the two glaciations recognized there and to determine their ages. Birman (1964) expanded on some of the criteria for use in the Sierra Nevada, and Burke and Birkeland (1979) have further developed and quantified these and other relative dating (RD) methods.

It is my purpose in this study to reexamine the criteria used by Blackwelder and by Sharp, to quantify some of them, and to use soil-profile descriptions and soil-analytical data in an effort to improve our knowledge with respect to the ages of the glacial deposits of the Ruby Mountains- East Humboldt Range. Field observations were begun during brief visits to the range in July 1974 and 1975, and additional data were collected, particularly in Lamoille and Hennen Canyons and at Angel Lake, during the summers of 1976 through 1979. Since Sharp's study of the Ruby Mountains, new and more detailed topographic maps, and aerial photographs, which facilitate field studies, have become available. Cuts along the U.S. Forest Service road in Lamoille Canyon expose both Lamoille and Angel Lake tills and the soil profiles developed in them, and gravel pits north and west of Lamoille, Seitz, and Hennen canyons make possible the examination of outwash deposited beyond the mouths of these valleys during the glaciations.

Climate and Vegetation

The Ruby Mountains rise from a piedmont slope with an altitude of 1830 m to crests exceeding 3350 m. Mean annual precipitation recorded at the station at Lamoille, altitude 1760 m, is 259 mm and mean annual temperature is 6.8°C. Values estimated for higher parts of the range are based on formulas developed at the LJ .S. Soil Conservation Service regional laboratory (**Table 1**). Vegetation at the base of the mountain is the Great Basin sage assemblage. On the north-facing slopes within the mountains, aspen and juniper appear at an altitude of 1970 m. Mountain mahogany becomes common on the valley floor and on slopes from 2140 to 2450 m, and at higher altitudes (2600 m and above) limber pine appears. No true upper tree line exists, but trees are sparse above 3200 m, largely because most of the terrain above that altitude is rock outcrops and scree. The character of weathering on exposed boulders will differ under different vegetational conditions. The present vegetation on Angel Lake moraines, which are well within the canyons and at elevations of 2075 m or higher, is mostly open forest of mountain mahogany and mixed conifers with an understory of sage and grasses. In contrast, Lamoille moraines extend farther down the valleys and onto the Piedmont as low as 1850 m at the mouth of Lamoille Canyon where the vegetation is the sagebrush assemblage.

In addition to these glacial erosional phenomena, some of the higher parts of the Ruby Mountains and much of the East Humboldt Range show evidence of past intensive frost action. Stone stripes and

Table 1. Temperature and precipitation calculated for higher altitudes in the Ruby Mountains

Altitude (m)	Mean annual precipitation (mm)	Mean annual temperature (°C)
3350	2490	2.1
3050	2060	3.1
2750	1620	4.1
2450	1190	5.1
2140	760	6.2
1830	325	–
1760	250	6.8

garlands are particularly common on the slopes that were above the surface of the Angel Lake glaciers in the East Humboldt Range, and sorted circles developed on a few of the summits at the north end of the range. Small relict rock glaciers are present below many cirque walls as far south as the cirque group south of Pearl Peak (40°12'N lat.). String bogs have developed on many of the cirque and higher valley floors.

Geomorphic characteristics of the glaciated regions

Glacial Erosional Forms

Viewed from a distance, the higher elevations of the Ruby Mountains clearly show the effects of a recent glaciation. The erosional features left after the disappearance of the younger, or Angel Lake, glacier include sharply cut cirques and arêtes, tarns, and steep-walled U-shaped valleys. Polished, striated, and chatter-marked rock surfaces are present on many cirque floors, thresholds, and rôche moutonnée, although few can be seen in the lower regions reached by Angel Lake ice. All of the rock exposures except marbles are fresh and show little weathering. Streams have cut narrow slots through the rock floor at thresholds but have not trenched the flat valley floors.

In addition to these glacial erosional phenomena, some of the higher parts of the Ruby Mountains and much of the East Humboldt Range show evidence of past intensive frost action. Stone stripes and garlands are particularly common on the slopes that were above the surface of the Angel Lake glaciers in the East Humboldt Range, and sorted circles developed on a few of the summits at the north end of the range. Small relict rock glaciers are present below many cirque walls as far south as the cirque group south of Pearl Peak (40°12'N lat.). String bogs have developed on many of the cirque and higher valley floors.

At lower altitudes than those reached by the Angel Lake glaciers, valleys that were modified only by Lamoille ice still retain the cross-sectional shape of a glacial trough, but it is ragged because weathering, erosion, and deposition have modified the rock surfaces. Streams have trenched the former U-shaped valleys, leaving perched remnants of the glaciated floors. Some valley-head shapes in the southern part of the Ruby Mountains are suggestive of old cirques, but they have been highly modified by mass wasting. If these are cirques, they may have been eroded by Lamoille ice but not reopened by later Angel Lake glaciers.

Moraines

The most obvious glacial deposits in the Ruby Mountains-East Humboldt Range are the long, massive, lateral moraines of Lamoille age that extend onto the Piedmont slope in Lamoille Canyon and the valleys south of it on the west side of the Ruby Mountains (Figs. 2, 3a). Similar ridges reach the Piedmont below Angel Lake on the east side of the East Humboldt Range. These lateral moraines have sharp crests that slope down valley about 11° and their side slopes are 17° to 20°. They show little hummocky topography; rather, they seem to have been smoothed by sheet wash and mass wasting, and their surfaces are covered with a veneer of grus.

A series of low, arcuate, end-moraine ridges extends onto the Piedmont around the mouth of Lamoille, Seitz, Hennen, and Rattlesnake canyons and below Angel Lake. The topography of these end moraines is gently rolling, but they are drained and exhibit no closed depressions. The distal margin of the outermost moraine at Lamoille Canyon is 1.6 km from the mountain front (Figs. 2, 4a) and stands about 1850 m above sea level. Successively younger ridges are present to the mouth of the canyon. Similar morainal ridges are present on the Piedmont at Seitz Canyon, but those at Hennen Canyon are indistinct and were not recognized previously.

Large angular boulders lie partly buried in the surface of the fan-shaped slope at the mouth of Hennen Canyon for a distance of about 500 m below the scarp that makes the mountain front. In this zone, three indistinct but discernable ridges that circle the mouth of the canyon can be detected on air-photos. The mean gradient of the fan is 7°, the distal parts of the ridges slope are 9 to 10°, and the slope is 5° between the ridges. The fan continues with a uniform gradient and all boulders on its surface are smaller and rounded below these three subtle ridges.

From Lamoille Canyon southwestward to Brennan Canyon (**Fig. 2**), the lower ends of all the large lateral moraines have triangular facets, most noticeably at Hennen Canyon. These faceted moraine spurs,

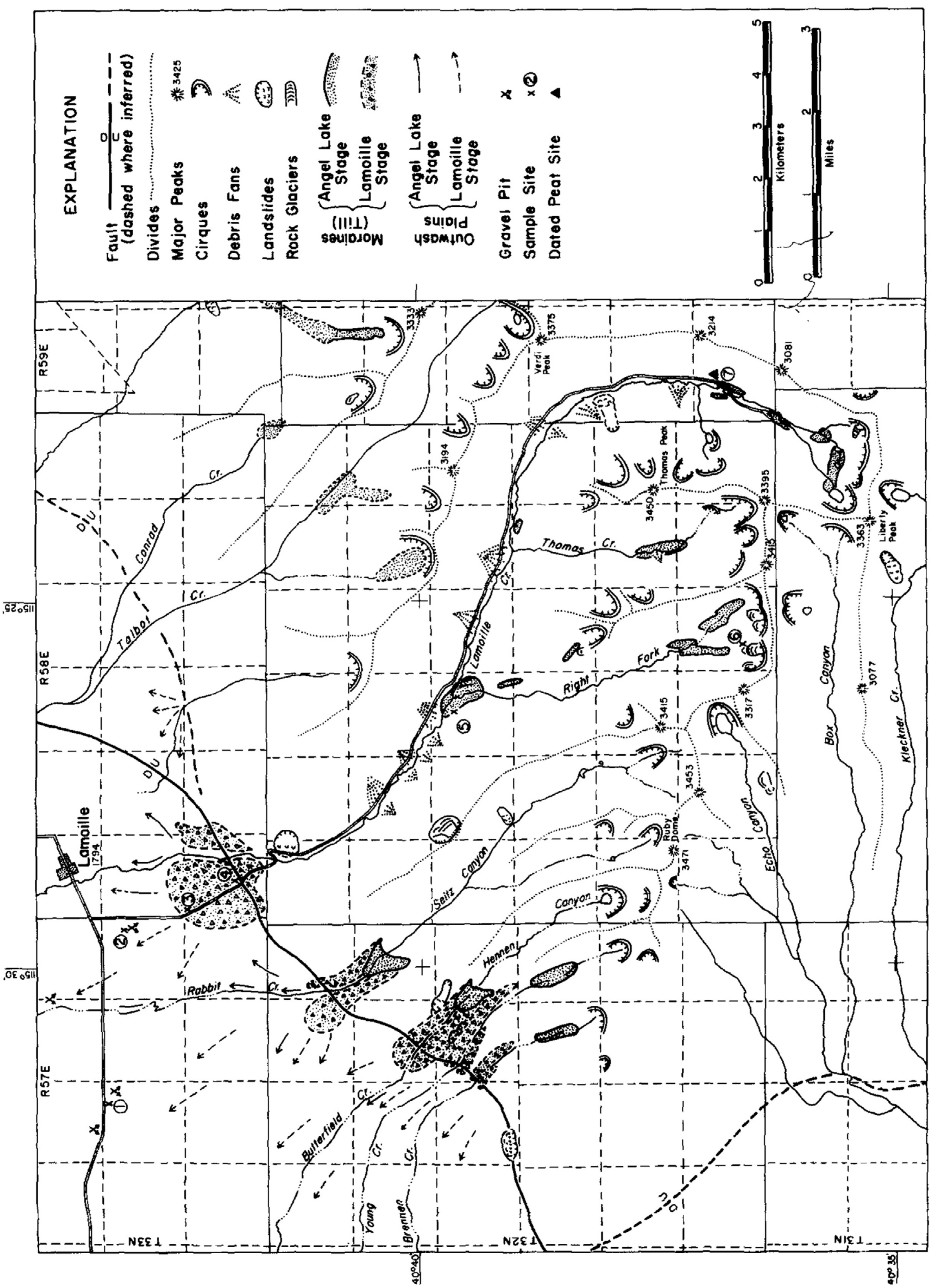

Fig. 2. Map of Lamoille Canyon area showing selected major geomorphic features and soil sample sites. Base from U.S. Geological Survey Lamoille and Lee quadrangles, scale 1:62,500.

coupled with springs and seeps along the mountain front, confirm the existence and position of a fault recorded by Sharp (1939) that has been active at least once since disappearance of the Lamoille-age glaciers. It has dropped the Lamoille end moraines at the mouth of Hennen Canyon so far as to nearly obscure them and has offset younger Angel Lake outwash where it leaves the canyon (**Fig. 3**a).

The hummocky and bouldery moraines of the Angel Lake glaciation show little modification by water erosion or mass wasting (Fig. 3b). Closed depressions and small ponds are present in many of the areas of Angel Lake drift, and the moraine surfaces are more abundantly covered with boulders than are those of Lamoille age. The streams flow out through narrow trenches in the end moraines, whereas the cuts through the moraines of Lamoille age are much wider. Nowhere do these younger moraines extend as far down the valleys as do the deposits of the older, Lamoille glaciation. In most valleys, too, few moraines are present above the main cluster of ridges that marks the maximum advance of Angel Lake ice (Fig. 3b).

Outwash Plains

A plain underlain by outwash gravel slopes smoothly northwestward for more than 3 km from the Piedmont moraines of the Lamoille glacier at the mouths of Lamoille, Seitz, and Hennen canyons, and Lamoille and Rabbit creeks have entrenched their channels 8 to 10 m beneath its surface. Gravel pits expose the sediments that underlie this trenched outwash plain (Fig. 2). The meltwater currents carried extremely coarse materials for at least a short distance. For example, a gravel pit 900 m north of the outermost Lamoille end moraine contains abundant large boulders, many of which are more than 25 cm in diameter; about 40% of the clasts are greater than 5 cm in diameter.

Three gravel pits 4 km northwest of the end moraines (Fig. 2) expose moderately well-sorted, cross-bedded gravelly sand in which rounded pebbles are entrained throughout the sand. The cross bedding and depositional characteristics of the sediment are that of a heavily loaded river that has continuous but fluctuating flow, such as a glacial meltwater stream. In contrast, sediments carried by modern ephemeral streams and deposited as alluvial fans in arid regions such as east-central Nevada generally are poorly sorted subangular gravel

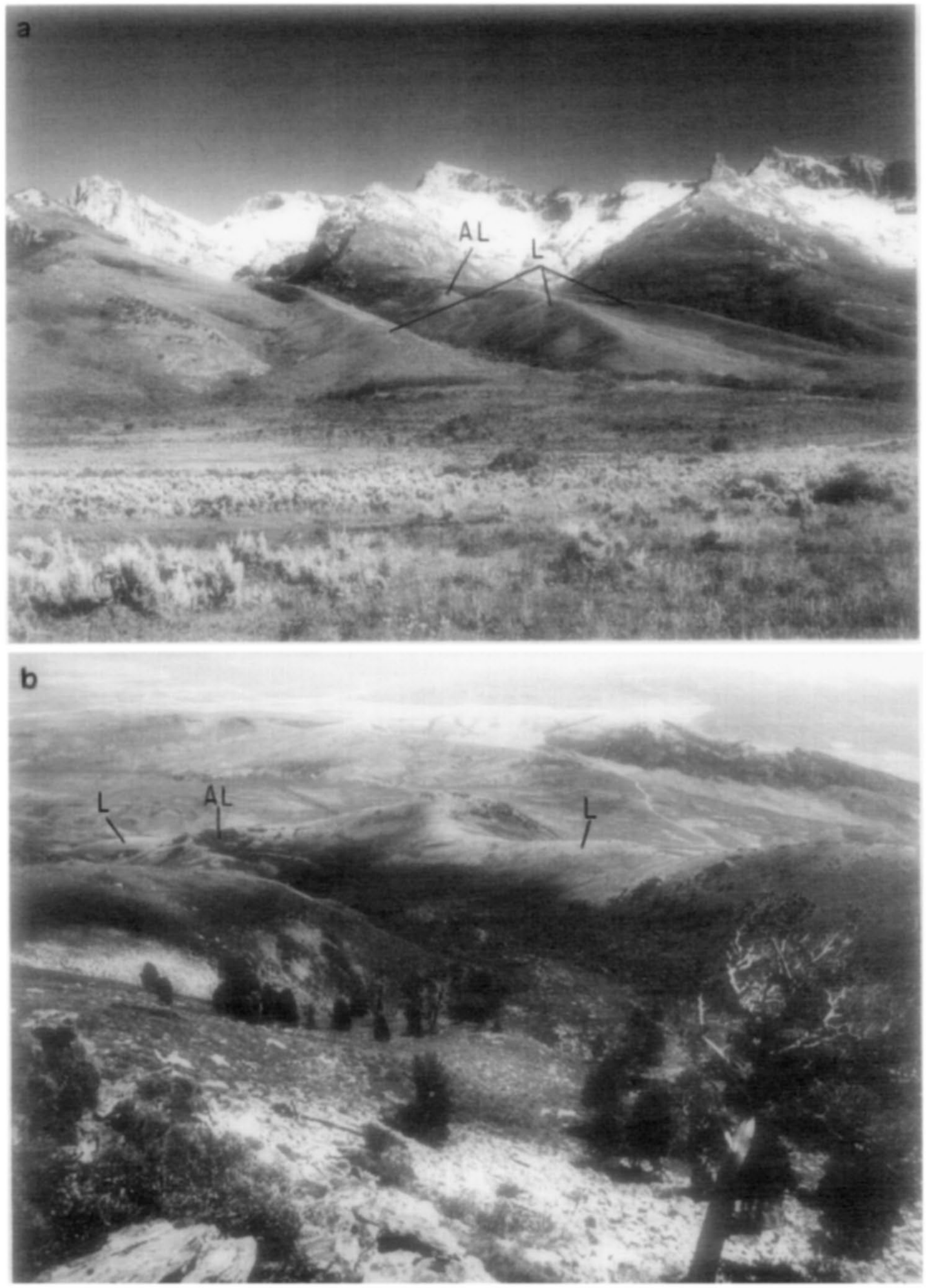

Fig. 3. Lamoille (L) and Angel Lake (AL) morainal topography. (a) Hennen Canyon. Fault scarp base marked by line of trees; top of fan below scarp is Lamoille end moraines nearly obscured by Angel Lake outwash. (b) Valley north of Angel Lake. Only a few small moraines are found in most valleys above the well-developed end moraines of the Angel Lake glaciation.

with a high silt component. A thin accumulation of poorly sorted fan debris overlies the cross-bedded gravelly sand in all of these gravel-pit exposures; the strongly developed soil profiles have formed in it and into the underlying materials. I have interpreted these well-sorted sediments to be outwash from the Lamoille glacier that is capped with some early post-Lamoille nonglacial fan sediments. Outwash from Angel Lake glaciers does not have the fan-like distribution of Lamoille outwash, but is restricted to montane valleys and to flat-floored valleys, such as those of Lamoille and Rabbit creeks, through the Lamoille outwash plain (**Fig. 4**a). Angel Lake outwash in the trough between the Lamoille lateral moraines in Hennen Canyon is very bouldery, and similar boulders are scattered over the fan below the obscure Lamoille end moraines. At the mouth of the canyon the outwash has been offset by faulting.

Weathering characteristics

Soil-Profile Development

The principal RD characteristics compared in this study are soil-profile development and surface and subsurface boulder weathering. The most maturely developed soil profiles generally are found on relatively level sites. Unfortunately, however, few level sites exist in the moraines, but some slopes on the end moraines are gentle, and soil profiles formed on them probably are diagnostic of the development that has taken place since deposition. Lateral moraines are steep and have a sharp crest; soil pits dug into the crests of the massive Lamoille lateral moraines at both Hennen Canyon and Angel Lake showed fresh till at a depth of 25 to 30 cm with no observable increase in clay and no structural development in the thin color-B horizon, so erosion must be removing weathered material from these surfaces as rapidly as it forms.

Cuts along the road up Lamoille Canyon have exposed the soil profile beneath each of the three end moraine ridges there, and Lamoille Creek has undercut its banks in several places, exposing part or all of the weathering profile. Gravel pits and stream banks provided exposures of the outwash beyond the moraines that were examined. Where suitable exposures did not exist, pits were dug. Soil data for significant

Fig. 4. Lamoille end moraine and outwash pattern, and soil profile on Lamoille till. (a) Drainage pattern on Lamoille outwash beyond end moraines at Lamoille canyon; dashed line marks boundary between till and outwash. Angel Lake outwash is confined to tree-covered strip along Lamoille Creek. (b) Soil profile on Lamoille Stage till in road cut through outermost end moraine.

profiles are summarized in **Tables 2 and 3**; locations of sampled and described sites are shown in Figure 2.

The soil profile exposed along the crest of the outermost morainal ridge in Lamoille Canyon (Fig. 4b) shows a distinct increase in clay in the B horizon, in which clay constitutes 40% of the material (**Fig. 5**). A well-developed blocky ped structure, dark brown color (7.5 YR 4/4), and thickness (24 cm) of the B2t horizon suggest considerable time has been involved in the formation of the solum on this till. The dominant clay minerals in both the B2t and B3tk horizons are montmorillonite and vermiculite; moderate amounts of kaolinite and illite also are present. Biotite, pyroxene, and hornblende grains show considerable weathering. Profiles with similar characteristics with respect to texture, color, and clay mineralogy (Fig. 5) have formed on the outwash sand and gravel just beyond the outermost end moraines of both Lamoille and Seitz canyons, although the more permeable gravel deposits at the somewhat lower altitude show Stage IV development of carbonates in the base of the solum as well as a strongly developed prismatic structure in the B horizon. At all of the sampled localities part of the fine material in the profile probably is wind-deposited silt.

Post-Angel Lake soil development is relatively weak (Fig. 5). In both of the sampled profiles and all other sites examined, the A horizon has been developed in silt that is virtually free of sand and pebbles, and that probably is largely loess. For both profiles analyzed the highest clay content is in the A horizon and is dominantly mica, although the B horizon contains more clay than does the unaltered till beneath it (Fig. 5). Pyroxenes and hornblende in the pedon show some etching along the edges. The B2 horizon is thin, dark yellowish brown (10 YR 4/4), and displays no distinctive ped structure; clay skins are absent. The total thickness of the solum is rarely greater than 40 cm (Tables 2 and 3).

Boulder Weathering

The degree of weathering of exposed boulders, particularly of granitic rocks, was used by both Blackwelder (1931) and Sharp (1938) to estimate relative ages of moraines in the Ruby Mountains. More recently, Burke and Birkeland (1979) provided more data on techniques of quantifying boulder weathering on moraines. Some of those techniques, modified because geologic conditions in the Ruby Mountains differ from those of the Sierra Nevada, were used in this study.

Table 2. Summary of field and laboratory data for soil profiles described and analyzed

Site	*Sediment*	*Age*[a]	*Horizon*	*Depth (cm)*	*Color (moist)*	*Texture*[b]	*>2 mm*[c] *(%)*	*<2 mm fraction (%) Sand*	*Silt*	*Clay*	*pH*	*Remarks*
1	Outwash	L	A	0-18	10 YR 6/2	L	5	39.5	37.2	23.3	8.1	
			B1	18-40	10 YR 5/3	L	5	39.5	41.8	20.7	8.0	
			2B2t	40-63	7.5 YR 5/4	CL	5	30.3	19.3	50.4	8.1	Strong prismatic structure. clay films distinct
			2B3k	63—85	10YR 7/4	SiL	5	34.9	22.3	42.8	7.9	
			2Ckm	85-90+	10YR 7/4	SiL	5	46.2	35.1	18.7	8.5	Strongly cemented, laminated
			2Ck	90-130	7.5 YR 8/2	GS	10					
			2C	130-	2.5 Y 6/4	GS	10					
2	Outwash	L	A	0-23	10 YR 5/3	L	5	23.2	48.9	27.9	8.0	
			B1t	23-40	10 YR 6/3	L	5	25.0	51.1	23.9	8.0	Weak blocky structure
			B2t	40-62	7.5 YR 5/4	CL	0	19.6	38.3	42.1	8.2	Strong prismatic structure, clay films distinct
			B3k	62-95	10YR 7/4	SiCL	0	23.6	36.9	39.5	8.2	
			2Km	95-125	7.5 YR 7/4	SiL	5	82.6	9.5	7.9	7.9	Laminated. cemented
			3Cox	125-425	7.5 YR 6/6	SG	80	89.9	3.1	7.0	7.5	Weakly cemented
3	Till	L	A1	0-6	10 YR 5/2	L	0	43.3	39.2	17.5	8.0	Probably loess
			A2	6-20	10 YR 4/3	SL	5	42.7	35.6	21.7	7.6	Probably loess
			B1t	20-38	7.5 YR 4/4	SCL	5	48.1	25.5	26.4	7.4	Weak blocky structure
			2B2t	38-62	7.5 YR 4/4	SCL	10	47.9	11.7	40.4	8.0	Strong blocky structure. clay films distinct but thin CaC03 films on peds
			2B3tk	62-86	7.5 YR 414	SL	20	46.7	12.6	40.7	8.5	
			2Ck	86-150	7.5 YR 7/4	SL	50	S3.S	27.7	18.8	8.6	
			2C	150-	2.5 YR 5/4	GSSi	50	63.6	18.9	17.5	8.0	
4	Till	L	A	0-12	10 YR 5/3	SL	10	S3.4	36.2	10.4	7.0	Loess
			2B2t	12-46	5 YR 4/4	GSCL	60	7S.3	9.1	15.6	7.1	Moderate strong blocky, clay films thin
			2C1	46-7S	10 YR 7/6	GSL	50	70.7	19.6	9.7	6.9	
			2C2	75-	10 YR 7/4 { 2.5 YR 7/4	GSL	40	69.3	24.2	6.5	7.5	
5	Till	AL	A1	0-11	10YR 3/4	SL	0	S3.4	30.1	16.5	6.9	Probably loess
			2A2	11-20	10 YR 3/3	GL	70	60.1	24.4	15.5	6.8	
			2B	20-30	10 YR 4/4	SL	50	70.7	19.1	10.2	6.6	
			2Cox	30-60	10 YR 5/4	GSiS	70	75.2	18.7	6.1	6.6	
			2C	60-	2.5 YR 6/4	SSi	60	81.6	13.2	5.2	6.1	
7	Till	AL	A1	0-7	10 YR 3/3	SSiOrg	0	41.1	37.2	21.7	6.2	Org. matter 30%
			A2	7-16	10 YR 6/3	L	0	41.6	40.4	18.0	5.9	Massive } loess
			B	16-42	10 YR 4/4	L	0	43.7	41.2	IS.I	5.7	Massive
			2Cox	42-64	10 YR 5/6	GL	25	68.3	25.6	6.1	5.8	Till
			2C	64-200+	2.5 YR 5/6	GSSi	60	84.8	11.5	3.7	5.8	Till

a. L: Lamoille; AL: Angel Lake.
b. G:. gravel; S: sand; Si: silt; L: loam; C: clay; Org: organic.
c. Field estimate of volume of material > 2 mm in size.

Table 3. Locations and descriptions of sites of analyzed soil profiles

Site	*Location and description*
1	NE corner NW¼ NE¼ Sec. 27, T33N, R57E; pit dug into bank of ditch about 320 m W of intersection of Elko-Lamoille Rd. with Pleasant Valley Rd., NW of small gravel pit; slope 3 to 5% to SW, vegetation cover about 60%, sage and grasses; altitude 1770 m
2	NE¼ NE¼ Sec. 25, T33N, R57E; bank of irrigation ditch about 30 m W of highwall of gravel pit, about 400 m S of intersection of Elko-Lamoille Rd. and Lamoille Canyon Rd.; slope 3 to 5% to E, vegetation cover about 70%, sage and grasses; altitude 1800 m
3	NW¼ NW¼ Sec. 31, T33N, R58E; road cut through broad flat crest of outermost end moraine of Lamoille till NW of mouth of Lamoille Canyon; slope 3% to SW, vegetation cover 75%, grasses and sage
4	NE¼ NW¼ Sec. 31, T33N, R58E; bank of irrigation ditch cut through end moraine of Lamoille till 850 m NW of gaging station at mouth of Lamoille Canyon; slope 7 to 9% to N, vegetation cover 75%, sage and grasses; bare areas between plants grus-covered and 5 cm lower than surface at plants; altitude 1910 m
5	SW¼ NE¼ Sec. 16, T22N, R58E; road cut through outermost Angel Lake end moraine in Lamoille Canyon, 100 m NW of entrance gate to Camp Lamoille; slope 3%, vegetation cover 80%, sage. grasses, and mountain mahogany; altitude 2130 m
7	SW¼ NW¼ Sec. 31, T32N, R59E; road cut through small Angel Lake moraine near middle of Lamoille Canyon about 3.2 km below head of canyon and 1.1 km N of parking lot at end of canyon road; vegetation cover 90%, grasses, forbs, sage, and aspen; altitude 2640 m; radiocarbon date 13,000 ± 900 yr B.P. (NWU-108) from base of peat accumulation on this moraine

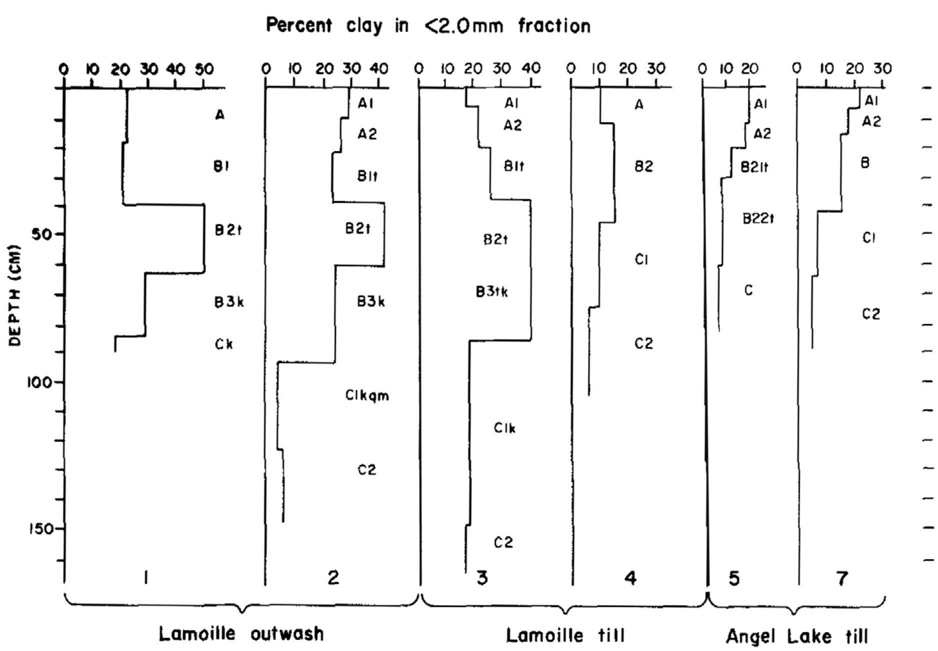

Fig. 5. Clay-particle-size variation with depth for post-Lamoille and post-Angel Lake soil profiles.

Rock types present in Ruby Mountain moraines include granites, pegmatites, granite gneisses, quartzites, schists, marbles, and calcareous and noncalcareous talc-silicate rocks. In most of the moraines, granites, granite gneisses, and pegmatites together make up 25 to 35% of the boulders present; quartzite cobbles and boulders dominate.

Both granite and granite gneiss boulders on surfaces of moraines of Lamoille age are strongly weathered and pitted (**Fig. 6**a) and are surrounded by a fringe of grus; pegmatite boulders are weathered into grotesque shapes, with large crystals of quartz or orthoclase standing out in relief. Quartzites show little etching, but the edges of the boulders generally are rounded, and many quartzite boulders have been split or fractured. Noncalcareous talc- silicate boulders are strongly weathered; boulders of diopside marble are absent from the surface of Lamoille moraines and are found only where relatively recent faulting or erosion has exposed a fresh surface of till.

As Sharp (1938, p. 302) pointed out, moraines of Angel Lake age are more bouldery than those of Lamoille age and contain abundant clasts of nonresistant rock types. Diopside marble, for example, is a common rock type and has a thin (5 mm) weathering rind. Other rocks, regardless of age, generally lack weathering rinds. Perhaps reduction of the granitic surfaces by granular disintegration progresses faster than does rind development on them. Granitic boulders on Angel Lake moraines are fully weathered and are subrounded, although they have shed little grus (Fig. 6b); some still show glacial polish and striae. Pegmatites are pitted and pits have a maximum relief of 10 cm. Quartzites are virtually unweathered.

The relative soundness of granitic boulders that are partly or entirely within the B horizon could be determined by striking them sharply with a hammer. All rocks checked for soundness were 20 to 30 cm in diameter. At each of four sites on Lamoille till and at three sites on Angel Lake till, ten granitic boulders within these size limits were examined and grouped into one of four weathering categories (**Table 4**). The study included only ten boulders at each site because granitic boulders in this size range were not sufficiently abundant to have included a larger number. The boulders in moraines of Angel Lake age show distinctly less weathering than do those of Lamoille age.

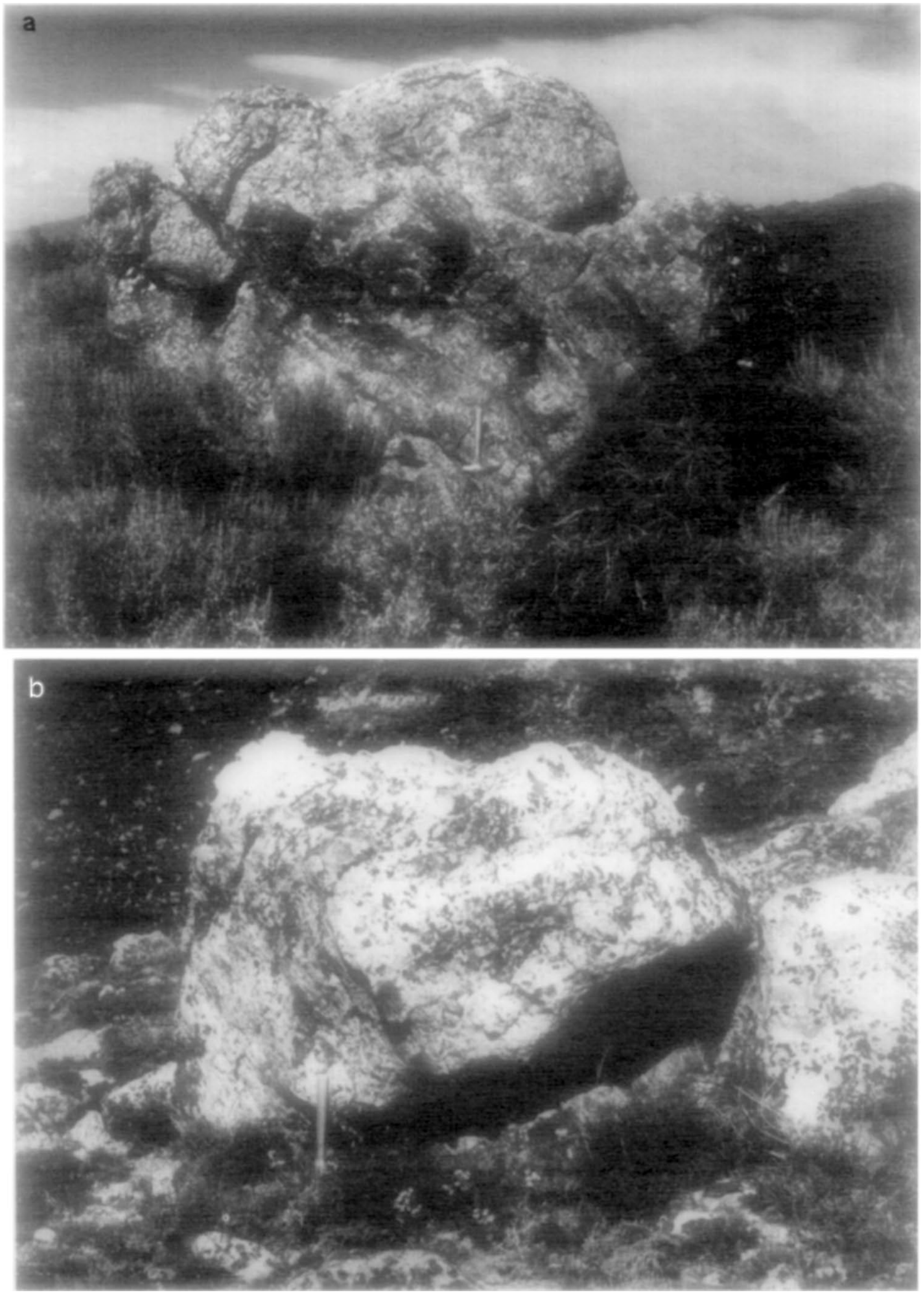

Fig. 6. Granitic-boulder weathering. (a) Boulder on crest of Lamoille Stage moraine below mouth of Lamoille Canyon. (b) Boulder on crest of outermost Angel Lake moraine at mouth of first valley south of Angel Lake.

Table 4. Degree of decomposition of granitic boulders in B horizon (n = 10)

		Degree of weathering[a]			
Moraine age	Sample site	A	B	C	D
Lamoille	Lamoille Canyon, end moraine, B horizon	0	0	8	2
	Hennen Canyon, right-lateral morainal crest	0	0	3	7
	Hennen Canyon, left-lateral morainal slope	0	0	0	10
	Angel Lake, right-lateral moraine crest	0	0	1	9
Angel Lake	Lamoille Canyon, end moraine crest, B horizon	9	1	0	0
	Hennen Canyon, end moraine crest	5	4	1	0
	Angel Lake, end moraine crest	10	0	0	0

a. Degree of weathering based on results of two moderately hard blows with a 24-ounce hammer: A, unweathered (untracked); B, slightly weathered (cracked); C, moderately weathered (broken); D, highly weathered (crushed to grus).

Alluvial Talus Cones

Alluvial talus cones, present in several canyons of the Ruby Mountains, contain both weathered and fresh rock debris, but once a cone is formed and stabilized, soil profiles develop in the material and the cone will be subject to erosion. Those in Lamoille Canyon and its tributaries higher than about 2600 m actively receive debris. Cones below that altitude, however, are stable and vegetated. The talus cones between 2600 and 2150 m, which is just beyond the outermost Angel Lake end moraine in Lamoille Canyon, have slopes of from 12 to 20°, many have gullies cutting them, and their soil profiles show little greater development than do the soils on the Angel Lake moraines. The B horizon is about 15 cm thick, brown (7.5 YR 3/2 to 4/4), and structureless. In contrast, the several alluvial talus cones below 2150 m in Lamoille Canyon have slopes of 8 to 17° and a clayey B horizon more than a meter thick that is strong brown (7.5 YR 4/4) and has blocky structure.

The soils suggest that these alluvial talus cones formed along the over-steepened walls of the canyon as the Lamoille ice melted and again following melting of the Angel Lake ice, but that downvalley more than a few hundred meters from the Angel Lake ice margin, the Lamoille alluvial talus cones evidently were not active again, even under full-glacial conditions, during Angel Lake time.

Discussion and correlations

Blackwelder (193 1) correlated the younger moraines of the western mountains, which he called Tioga, with the Wisconsin Stage and referred the older moraines (Tahoe) to the next-older stage in the midcontinent classification in use at that time, the Iowan. No constructional topography is present on the still-older Sierran till, the Sherwin (Sharp, 1968). Sharp (1938, pp. 307-309) discussed the possibility that the Lamoille tills should be correlated with Illinoian drift of the Great Lakes region, but concluded that neither the extent of postdepositional modification of the moraines nor the degree to which boulders on the Lamoille moraines had been weathered was adequate for an age as great as Illinoian. He argued further that were the Lamoille glaciation to be correlated with the Illinoian, moraines equivalent to the Tahoe glaciation of the Sierra Nevada, another area where no Illinoian equivalents had been recognized, should have been found in the Ruby Mountains. The Angel Lake drift was considered by all to be a Tioga and Wisconsin correlative.

Burke and Birkeland (1979) recently have examined the RD parameters of the glacial deposits of the Sierra Nevada. In an earlier study, Sharp and Birman (1963) had recognized five post-Sherwin glaciations, but Burke and Birkeland (1979) believed the differences they measured do not permit recognition of more than two first-order glaciations. Tills they studied in the Sierra Nevada have matrices much higher in sand and lower in clay than those of the Ruby Mountains, but the soil profile and weathering data of the Lamoille till compare favorably with those of the Casa Diablo till. Morainal form and postdepositional modification resemble those of Mono Basin and Tahoe tills. All three of these tills were grouped together under the name Tahoe, by Burke and Birkeland (1979). Dates for basalt that bracket Tahoe (Casa Diablo) tills are 129,000 ± 26,000 and 53,000 ± 44,000 yr (Burke and Birkeland, 1979, p. 29; Dalrymple et al., 1982).

Although Bull Lake deposits of the Rocky Mountains have long been considered early Wisconsin in age (Richmond, 1965), the soil profile and surface-weathering phenomena on some Bull Lake tills suggest greater age (Colman and Pierce, 1981). Shroba (1977) in the central and southern Rocky Mountains and Mahaney (1978) working in the Wind River Mountains used soils and other RD phenomena to differentiate Bull Lake, Pinedale, and three Holocene glacial deposits. They were able to distinguish deposits of stage level by each of the major RD techniques. Soil profile development on Pinedale and early Bull Lake deposits in the Rocky Mountains is similar to that on Angel Lake and Lamoille tills, respectively, in the Ruby Mountains of Nevada. Post-Pinedale soils in the Wind River Range are slightly thicker than the post-Angel Lake soils of the Ruby Mountains, and the B horizons have a weak blocky structure, whereas the B horizon of the post-Angel Lake soils is massive and not argillic (Table 2). Post-Bull Lake soils in the Wind River Mountains are ~150 cm thick, comparable to post-Lamoille soils, and B horizons of both have a well-developed blocky structure and 7.5 YR colors. These similarities suggest that the period of weathering for Pinedale and Angel Lake tills and for Bull Lake and Lamoille tills was comparable. Recent efforts to date Bull Lake and Pinedale tills in Montana (Pierce et al., 1976), by means of obsidian hydration and by weathering rinds (Colman and Pierce, 1981), indicate that in the west Yellowstone region Pinedale tills are from 29,000 to 35,000 yr old and that the Bull Lake tills are between 130,000 and 155,000 yr old. Pierce (1979) showed that post-Bull Lake soils of the dated deposits at west Yellowstone have development similar to those of other areas.

Differences in soil profiles, boulder weathering data, and morphologic changes for the Lamoille and Angel Lake tills and alluvial talus cones related to them in the Ruby Mountains are much greater than expected within the time generally accepted for the Wisconsinan age and suggest differences of stage magnitude (Birkeland et al., 1979). A single radiocarbon date from peat at the base of a small bog on a moraine (Fig. 2) helps fix the termination of the Angel Lake glaciation in the Ruby Mountains; Lamoille Canyon had become free of ice at 2640 m before 13,000 ± 900 yr B.P. (Nebraska Wesleyan University (NWU)-108). Because Angel Lake moraines show little alteration by either weathering or erosion, an estimate of about 20,000 yr, which corresponds to the maximum advance of the Wisconsinan ice sheet in the Great Lakes region, should be reasonable for the age of the outermost moraines.

Blackwelder (1931, p. 881) reviewed two earlier estimates for the differences in age of Tioga and Tahoe glacial deposits in the Sierra Nevada. He stated a preference for the greater one-that Tahoe moraines were five times as old as Tioga moraines, an estimate based on the depth of erosion along streams-although he conceded that he had little confidence in the accuracy of such estimates. Too little still is known about the changes in morphology, weathering, or soil development as a function of time to permit such parameters to be used as reliable indicators of absolute age. In a recent review of weathering rates, though, Colman (1981) showed clearly that they are nonlinear; rather, the rate of formation of a weathering residue is inversely proportional to its thickness. Shroba (1977), plotting certain solum characteristics as a function of time, found that the rate of change decreased with increasing age. Weathering-rind thicknesses on dated andesites and basalts were shown by Colman and Pierce (1981) to be logarithmic as a function of time. It would follow, then, that both the thickness of a solum and the degree of development of structure of its Bt horizon should be directly proportional to its age, but the rate of increase in both of these characteristics is inversely proportional to the length of time involved.

Because of the significant differences in weathering and erosion between the Lamoille and Angel Lake tills, I believe the difference in age to be greater than the factor of 5 to 1 considered by Blackwelder, and suggest that the Lamoille till may be as much as an order of magnitude older. Specific features that have led me to this conclusion are the differences in erosional modification of moraines and walls of glaciated valleys, the intensity of weathering of boulders, and the maturity of the sola on Lamoille till and outwash, which not only are two or more times thicker than those on Angel Lake till but also have considerably greater clay accumulation and more strongly developed structure in the Bt horizon. Thus, if 13,000 to 20,000 yr is taken as the probable age of the Angel Lake till, then 130,000 to 200,000 yr is considered a reasonable estimated maximum age for the Lamoille deposits. These dates fall within the same time framework as that determined by Pierce et al. (1976) for Bull Lake deposits.

The most complete record of the climatic changes of the Pleistocene is found in deepsea cores. Although different opinions exist as to which continental glaciation is represented by each of the cool periods, oxygen isotope and foraminiferal studies indicate that extensive storage of water in glaciers, accompanied by significant cooling of surface- water temperatures, took place between 180,000 and 125,000 yr ago and from about 70,000 to 10,000 yr ago (Shackleton and Opdyke, 1973; Fairbanks and Matthews, 1978). The change to cooler temperatures of 70,000 yr ago generally has been correlated with the beginning of the Wisconsinan glaciation. I believe it reasonable to correlate the cool period between 180,000 and 125,000 yr ago with the Illinoian glaciation. The existing dates on Pinedale and Bull Lake tills, with which the Angel Lake and Lamoille are correlated, fall into these periods, as suggested by Colman and Pierce (1981).

Perhaps part of the conflict that has long existed with respect to the correlation of Tahoe, Bull Lake, and Lamoille tills is based on old philosophies and semantic differences. In 1931, when Blackwelder correlated these alpine glacial deposits with the Iowan drift of the Great Lakes region, the Iowan was regarded as a major glaciation between the Illinoian and the Wisconsin (Alden and Leighton, 1915). At that time, however, Leverett (1926, 1929, 1939) was questioning the validity of the Iowan glaciation and argued that, if it existed at all, it should be nearer Illinoian in age than Wisconsin. Kay (1928) disagreed with Leverett and kept the Iowan as a separate glaciation. In 1933, Leighton set up a new classification for the Wisconsin Stage, in which he listed the Iowan as the first of four substages, a classification that was to affect correlations for nearly 30 yr. Ruhe (1969, pp. 93- 106) finally buried the problem when he demonstrated conclusively that the Iowan glaciation never took place. Sharp (1938), along with nearly all other glacial geologists at that time, undoubtedly accepted Leighton's interpretation of the Iowan (personal communication, 1983); he confirmed Blackwelder's correlations, so the Lamoille, along with the Tahoe of the Sierra Nevada and the Bull Lake of the Rocky Mountains, became "early Wisconsin."

One of the important arguments favoring a relatively greater age for Illinoian deposits was that few morainal or other constructional topographic features had been identified on the Illinoian drift plain of the type area (Leverett, 1899, pp. 26-27; Malott, 1922, pp. 141-143; Flint, 1947, p. 283). Later studies, however, indicate that even though they have been modified by erosion and veneered with loess, both end moraines and kames of Illinoian age are readily evident in southern Illinois (Leverett, 1930; Leighton and Brophy, 1961; Johnson, 1976) and southwestern Indiana (Gray et al., 1970). The Lamoille moraines of the Ruby Mountains-East Humboldt Range show comparable effects of weathering and erosion. It is my interpretation, based on soil profiles on the tills, the degree of weathering of the surficial boulders on them, and on the extent of constructional landform dissection, that only the Angel Lake till is Wisconsinan in age, and that the Lamoille deposits are more correctly correlated with the Illinoian of the Great Lakes region.

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