Quaternary Stratigraphy of the La Sal Mountains Utah

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QUATERNARY STRATIGRAPHY OF THE LA SAL MOUNTAINS, UTAH

By Gerald M. Richmond

ABSTRACT

General setting.—The La Sal Mountains are in southeastern Utah on the eastern margin of the Colorado Plateau, and just south of the confluence of the Colorado and the Dolores Rivers. They comprise three mountain groups that rise steeply above the general level of the plateau to altitudes as high as 12,700 feet. Each mountain group is underlain by laccolithic masses of diorite which, in Tertiary time, intruded the Triassic, Jurassic, and Cretaceous sedimentary rocks of the plateau radially from a central stock. The sedimentary rocks consist mostly of massive red sandstone, red siltstone, and gray shale.

Quaternary processes.—During the Quaternary period, the La Sal Mountains were glaciated at least 9 times. The glaciers were all small, the largest being only 9 miles long. Each glacial episode was characterized by extensive glacial, alluvial, colluvial, and eolian sedimentation. Colluvial sedimentation was predominantly the product of frost action and solifluction. The early part of each interglacial interval was characterized by fine-grained alluviation and eolian activity followed by local arroyo-cutting; the middle part, by widespread slope stability and weathering or soil profile development; the latter part, by extensive deepening and widening of valley floors by erosion prior to the onset of the next glacial episode.

Quaternary stratigraphy.—The Quaternary stratigraphy of the La Sal Mountains involves the relations of a variety of genetically different deposits to each other, to disconformities, and to ancient soils that range, with altitude, through several great soil groups, or facies. Recognition of the differences between soils of different geologic age proved particularly significant as a means of local correlation of deposits; but other means of correlation were also fully utilized, including relative topographic position, surface expression, internal character, and relation to erosion surfaces and disconformities.

On the basis of these criteria, the Quaternary deposits of the La Sal Mountains are grouped into four formations. The upper surface of each formation is marked by a widespread distinctive soil that is locally truncated or cut out by a disconformity which also separates the formations.

Formations are subdivided into members, whose upper surfaces are also bounded by widespread soils, locally truncated or cut out by disconformities. The characteristics of soils that separate members, however, are not necessarily distinctive of a particular member.

Each formation and member comprises several genetically distinct facies whose intergradational or interfingering relations to a given formation or member can be clearly demonstrated.

The oldest formation, called the Harpole Mesa formation, consists of three members. The lower and middle members comprise three facies: till, alluvial gravel, and eolian sand and silt. These deposits lie on interstream divides, and genetically similar facies are so alike that they cannot be distinguished as to member except where superposed and separated by a soil, or where the alluvial facies lie on distinctly different erosion surfaces. The tills are thin sheets that retain only rare vestiges of morainal topography. The alluvial deposits trend across present canyons. The eolian deposits are interbedded with the tills and alluvial gravels or mantle them conformably.

The disconformity separating the middle member from the upper is of canyon proportions, and deposits of the upper member lie mostly in the canyons. However, these deposits locally overlap the older members on interstream divides and may be distinguished where all three members are in superposition and separated by soils. The upper member comprises eight facies. The till facies retains the broader aspects of morainal topography in many places. The alluvial gravel parallels the present drainage. The alluvial fans are deeply dissected and commonly beheaded. Talus, solifluction mantle and frost rubble are rarely preserved. Inconspicuous eolian deposits fill depressions on the uplands.

Each of the three members of the Harpole Mesa formation has a stratigraphically distinct but similarly very strongly developed zonal soil formed on it. These are called the lower, middle, and upper Spring Draw soils or, where undifferentiated, simply a Spring Draw soil. At any given altitude, these soils tend to be more strongly developed than other geologically distinct soils. Also, the boundary between their acid and alkaline facies (the pedalfer-pedocal boundary) is at a higher average altitude than those of other soils.

The Placer Creek formation locally overlaps the Harpole Mesa formation, but more commonly it rests on bedrock in valleys that dissect the Harpole Mesa formation to depths of 100 to 200 feet. It consists of a lower member and an upper member, and comprises 9 genetically distinct facies: till, alluvial gravel, alluvial sand and silt, alluvial-fan gravel, talus, solifluction mantle, frost rubble, slope-wash mantle, and eolian sand and silt. The stratigraphic relations of 5 of the facies to either the lower member or the upper member can be demonstrated in many places. The other 4 facies, however, can be related only to the formation as a whole.

In general, deposits of the Placer Creek formation are larger, more widespread, more mature in topographic aspect, more weathered, and more dissected than those of younger formations. The terminal moraines are mostly in the lower parts of the canyons and solifluction deposits extend nearly to the base of the mountains. A weakly developed zonal soil, known as the Porcupine Ranch soil, is preserved locally on the lower member where it is buried by the upper member.

A strongly developed soil, the Lackey Creek soil, is formed on the upper member and also on the lower member where it is not buried by the upper member. At any given altitude, the profile of this soil tends to be less strongly developed than the Spring Draw soils, but more so than the younger soils. The average altitude of the boundary between its pedalfer and pedocal facies

is lower than that of the Spring Draw soils but higher than that of any other soils.

The depth of erosion between the Placer Creek formation and the next younger formation, the Beaver Basin, averages from 30 to 50 feet.

The Beaver Basin formation lies on the Placer Creek or Harpole Mesa formations, in valleys that dissect them, or on upland bedrock surfaces. It consists of 2 members, and comprises 10 facies: till, rock glacier, alluvial gravel, alluvial sand and silt, alluvial-fan gravel, talus, frost rubble, solifluction mantle, slope-wash mantle, and eolian sand and silt. The stratigraphic relations of 6 of the facies to the lower or upper members can be clearly demonstrated; 4 can be related only to the formation as a whole.

The terminal moraines of both members lie farther upstream than the terminal moraines of the Placer Creek formation. In some canyons they are represented by rock glaciers. Two generations of frost rubble and two of alluvial gravel are distinguishable on the basis of their geomorphic relations. A weakly developed zonal soil, the Pack Creek soil, is commonly preserved at the top of the lower member where it is overlain by the upper member.

A moderately developed zonal soil, the Castle Creek soil, is formed on the upper member and on deposits of the lower member that are not buried by the upper member. At any given altitude, this soil tends to be less well developed than the Spring Draw or Lackey Creek soils but better developed than all other soils. The average altitude of the boundary between its pedalfer and pedocal facies is lower than that of the Spring Draw or Lackey Creek soils, but higher than those of any others.

The depth of erosion between the Beaver Basin formation and the youngest formation, the Gold Basin formation, averages from 15 to 30 feet.

The Gold Basin formation commonly lies in channels that truncate the Beaver Basin formation, or on bedrock. It consists of 2 members and comprises 10 facies: till, rock glaciers, alluvial gravel, alluvial sand and silt, alluvial-fan gravel, talus, frost rubble, solifluction mantle, slope-wash mantle, and eolian sand and silt. Seven facies can be related specifically to the lower and upper members; three can be related only to the formation as a whole.

The Gold Basin formation is the least extensive of the Quaternary deposits. Moraines or rock glaciers are confined to the cirques, as is talus except for very small deposits along lower canyons. Alluvium forms narrow terraces along the present streams. Solifluction mantle and frost rubble are confined to the higher mountains. Slope-wash mantle is widespread but thin and spotty. Eolian deposits are also widespread, but are thick enough to map only on the plateaus and in the major valleys.

The lower member, whether buried or exposed, has a very weak azonal soil, the Spanish Valley soil. The upper member has no soil, or merely a faint humus horizon, and, except for its moraines and rock glaciers is still accumulating, at least intermittently.

Five of the 8 Quaternary soils in the area occur in 4 different facies, equivalent to great soil groups, that are ranged with altitude on the mountain slopes. These facies are, from higher to lower, Brown Podzolic soils, Brown Forest soils, Brown soils, and Sierozem soils. Though locally formed on older Pleistocene deposits and in some places on older rocks, each individual soil can be traced throughout its range of facies. Futhermore, each soil maintains its characteristic degree of development relative to other soils throughout its range of facies.

Correlation.—Assuming that the major factors in soil development are climate and the duration thereof, and that the major climatic fluctuations of the Quaternary were synchronous over the Rocky Mountains and the High Plains in the United States, the relative stratigraphic development and geologic succession of soils is believed to furnish a criterion for regional correlation. On this basis, the Harpole Mesa formation is correlated with the Cerro till of the San Juan Mountains, till of the Prairie Divide stage of Bryan and Ray (1940) of the Front Range, till of the Buffalo stage of the Wind River Mountains, and the Nebraskan, Kansan, and Illinoian (Loveland) deposits of the High Plains. Similarly the Placer Creek formation is correlated with the Durango till in the San Juan Mountains, tills of the pre-Home and Home stages of Bryan and Ray (1940), of the Front Range, till of the Bull Lake stage in the Wind River Mountains, and the Peoria loess of the High Plains. The Beaver Basin formation is correlated with till of the Corral Creek substage of Bryan and Ray (1940) in the Front Range, till of the Pinedale stage of the Wind River Mountains, the Jeddito formation of Hack (1942) in the Hopi Country, Arizona, and the Bignell loess of the High Plains.

The lower member of the Gold Basin formation is correlated with the Tsegi formation of Hack (1942) in the Hopi Country, an early Recent till in the San Juan Mountains, till of the Sprague substage of Ray (1940) of the Front Range, deposits in the Temple Lake moraine of Moss (1951a) of the Wind River Mountains, and an early Recent alluvium in Nebraska. Some of these deposits are also characterized by a prepottery stone culture and hearth sites. Charcoal from a hearth site in the lower member of the Gold Basin formation yields a radiocarbon age of $2{,}800 \pm 200$ years. The upper member of the Gold Basin formation is correlated with the Naha formation of Hack (1942) in the Hopi Country, a late Recent till in the San Juan Mountains moraines in front of existing glaciers in the Front Range and Wind River Mountains, and a late Recent alluvial terrace in Nebraska. Some of these deposits contain pottery.

Quaternary history.—The succession, character, and stratigraphic relations of the deposits, soils, and disconformities in the La Sal Mountains demonstrate that events in one glacial-interglacial cycle were repeated in considerable detail in the others. Variations were chiefly due to differences in either intensity or duration of processes controlled largely by climate and time. The climate at any given time varied with altitude on the mountains, and changed progressively with time.

The events of each cycle are inferred to have been as follows:

1. Early glacial (increasingly wet and cold). During the initial advance of glaciers, stream regimen changed from erosion to alluviation. Increasingly intense frost action increased the rate and extent of formation of talus, solifluction deposits, and frost rubble, and together with the prevailing low temperature effectively decreased the rate of soil profile development. Vegetation zones were lowered.
2. Middle glacial (cold and wet). At the glacial maximum, the terminal moraines seen today were formed. Frost action and solifluction were maximal, and coarse alluvium extended throughout the major valleys. Tree line was at a minimum altitude.
3. Late glacial (cool and increasingly dry). The ice shrank chiefly through ablation. Solifluction and frost-rubble deposits gradually stagnated; talus continued to form. Alluviation of fine-grained debris and eolian activity dominated at lower altitudes. Vegetation tended to become sparse.
4. Early interglacial (dry and increasingly warm). At the beginning of an interglacial the glaciers disappeared completely; solifluction and frost-rubble deposits stabilized. Talus formed at a reduced rate in the cirque heads. Eolian de-

position extended to the summits. Fine-grained alluviation persisted for a time in the lower valleys but changed gradually to arroyo cutting. Vegetation zones started to rise.

5. Middle interglacial (warm and moist). The middle part of an interglacial interval was marked by intensive soil development on stable slopes and a tendency for pedocal soil-forming processes to migrate upslope. Streams bypassed material with little erosion or deposition. Tree line was at a maximum altitude.
6. Late interglacial (increasingly cooler and wetter). The latter part of an interglacial interval was characterized by stable slopes with relatively dense vegetation. Pedalfer soil-forming processes tended to migrate downslope. An increase in the erosional activity of streams caused significant deepening and widening of valley floors. Vegetation zones started to move down.

Certain differences in extent and intensity of process from one glacial-interglacial cycle to another are significant.

1. Harpole Mesa glaciations. The three glaciations represented in the Harpole Mesa formation were of similar size and considerably more extensive than later ones, probably reflecting colder and wetter conditions. All three formed piedmont ice at the foot of the mountains.

   The first glaciation preceded canyon development; the second advanced on a relatively deep, broad-valley erosion surface; the third took place after considerable canyon incision and was followed in the subsequent interglacial interval by further canyon-cutting. The downcutting was sufficient to suggest that it was in part due to epeirogenic uplift of the Rocky Mountains region. However, as it was interrupted by climatic alluviation during each glaciation, the uplift was probably very gradual.

   The very strong development of all three Spring Draw soils and the range in altitude of their pedocal facies suggest that the soil-forming optima following each glaciation were similar and all were longer and warmer than any succeeding interglacial intervals.
2. Placer Creek glaciations. The two glaciations represented in the Placer Creek formation were confined to the mountain canyons. Solifluction processes extended to most of the mountain slopes but frost rubble was very localized. Eolian activity toward the close of glaciation affected most of the area.

   The weakly developed character of the Porcupine Ranch soil suggests that the interval separating the two glaciations was short and somewhat warmer and wetter than at present. The strong development of the Lackey Creek soil and the range in altitude of its pedocal facies suggest that the soil-forming optimum following the later Placer Creek glaciation was longer and warmer than any subsequent interstadial interval but not as long nor as warm as those in which the Spring Draw soils formed.
3. Beaver Basin glaciations. The two glaciations represented in the Beaver Basin formation were confined to the upper parts of canyons, suggesting that the climate was either not as cold or not as wet as during the Placer Creek time. Solifluction was relatively restricted, but frost-rubble development was widespread. Eolian activity was confined mostly to the west slope of the mountains.

   The weakly developed character of the Pack Creek soil suggests that the interval separating the two glaciations was short and somewhat wetter than at present. The moderate development of the Castle Creek soil and the range in altitude of its pedocal facies suggest that the soil-forming optimum following the later Beaver Basin glaciation, the "altithermal" interval of Antevs, was not as long nor as warm as that following the later Placer Creek glaciation but was considerably warmer than at present.
4. Gold Basin glaciation. Glaciers and rock glaciers of the earlier Gold Basin glaciation were restricted to the cirques; solifluction and frost-rubble development was restricted to summit areas. These conditions suggest that the glacial episode was short and only slightly colder and wetter than at present. Valley alluviation was characterized by fine-grained sediments, in contrast to the widespread gravel deposition of earlier glaciations.

   The very weak development of the Spanish Valley soil and the range in altitude of its pedocal facies suggest that the soil-forming optimum following glaciation was very short and only slightly warmer than at present.

   Glaciers and rock glaciers of the later Gold Basin glaciation were even smaller than those of the earlier, and periglacial processes comparably restricted in extent under the less cold and wet climatic conditions. The currently decreasing range of frost action, widespread arroyo-cutting, and increasingly dry climatic conditions suggest that the present may be part of an interglacial interval of indeterminate duration.

INTRODUCTION

The La Sal Mountains in southeastern Utah are extensively mantled by Quaternary deposits that range widely both in genesis and age. These deposits were studied because they appeared to offer unusual opportunity to investigate problems in Quaternary stratigraphy and correlation, whose solution would have broad application both within and beyond the Rocky Mountain region.

This report is primarily devoted to a description of the Quaternary deposits and soils and to an analysis of their stratigraphic relations. The deposits include nine different generations of glacial, alluvial, colluvial, and eolian sediments. Each generation is separated from the succeeding one by an ancient soil and also by a disconformity or an erosion surface. However, the deposits, soils, and disconformities or erosion surfaces are nowhere superposed in a vertically continuous column, and determination of their succession therefore required detailed study of both their stratigraphic and geomorphic relations. Plate 1 is a geologic map of the Quaternary deposits, and plate 2 a reconnaissance map of the soils.

In the latter part of the report the local Quaternary deposits are correlated with those of other areas of the Rocky Mountains and the High Plains. The final section is an interpretation of the Quaternary history of the La Sal Mountains in terms of inferred changes in regimen of geologic processes, ecology, and climate.

LOCATION OF THE AREA

The La Sal Mountains lie in southeastern Utah south of the confluence of the Colorado and Dolores Rivers (fig. 1). The area mapped lies between lat

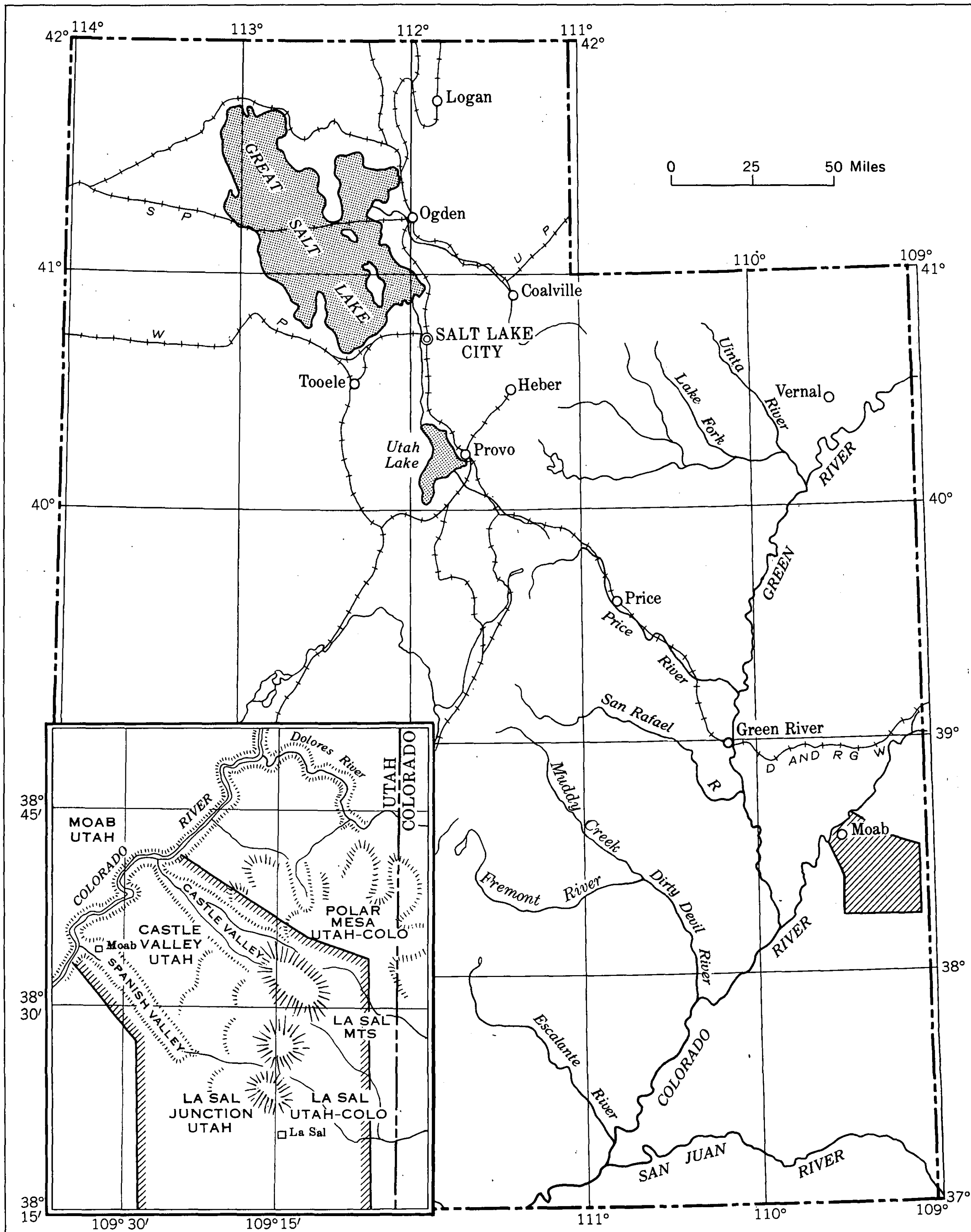


FIGURE 1.—Index map showing location of the La Sal Mountains in southeastern Utah.

38°15′ and 38°40′ N. and long 109°00′ and 109°30′ W., and it includes approximately 550 square miles. It is covered by the following 15-minute quadrangles: Polar Mesa, Utah-Colo., Castle Valley, Utah, La Sal, Utah-Colo., La Sal Junction, Utah, and Moab, Utah.

NATURE OF PRESENT WORK

Field studies were carried out in July and August 1949, from June through September 1950, and in August 1952. The Quaternary deposits were examined at roadcuts and such natural exposures as stream banks, arroyo walls, or escarpments. In many places, however, test pits were necessary to secure critical stratigraphic information, to collect data on soil profiles, or to determine the origin of certain kinds of deposits. More than 300 such pits were dug, of which more than 100 were 4 to 6 feet deep. Attempts to drill with an auger were nearly useless in the extremely stony terrain.

Inasmuch as adequate topographic maps of the area were not available until after the manuscript was written, the geology was mapped on aerial photographs at a scale of approximately 2 inches equals 1 mile (1:31,680), on which the section corners were located in the field. This information was later transferred to controlled aerial mosaics, prepared at the same scale by the U.S. Department of Agriculture, Soil Conservation Service, 1947, and from these a planimetric geologic map was traced. The planimetry was checked against land plats compiled by the U.S. Department of Interior, General Land Office (now Bureau of Land Management); existing planimetric maps compiled by the U.S. Department of Agriculture, Soil Conservation Service; and the land net of topographic strip maps along the Colorado River, surveyed by the U.S. Geological Survey. Subsequently, after the manuscript had been edited, a check made against newly available U.S. Geological Survey topographic maps revealed some errors, especially in the higher mountains in the vicinity of Mount Peale. These errors still exist on the map, as planimetric revision of the geology was not feasible.

During the preparation of the manuscript an attempt was made to construct crude topography with a contour interval of 200 feet for the area, using as a base existing topographic strip maps along the Colorado River, the La Sal quadrangle of the Hayden and Powell Survey, 1885, and a topographic sketch map of the La Sal Mountains by C. B. Hunt. However, this attempt proved inadequate when checked against the new topographic maps, which were ultimately used to recompile the 200-foot contours on plates 1, 2, 4, and 6 of this report, and from which all elevations in the text and illustrations have been recomputed.

ACKNOWLEDGMENTS

This investigation was made at the same time as a study of the bedrock geology by C. B. Hunt, with resulting discussions and exchange of information that proved extremely useful. In 1950 I was visited in the field by Ray C. Roberts and W. G. Harper, of the U.S. Department of Agriculture, who assisted materially in identifying the boundaries between great soil groups. Prof. W. O. Thompson, of the University of Colorado, reviewed the Quaternary stratigraphy of the area in 1950, and Prof. H. T. U. Smith, of the University of Kansas, visited the area to discuss the classification and origin of the various kinds of frost-rubble deposits in 1952.

Eugene Hunt volunteered as assistant during the season of 1949, and B. J. O'Neill, Jr., and Lyman Allen III served as assistants in 1950 and 1952, respectively. The many courtesies and friendly association of Effie and Gordon Fowler, of Miners Basin, Q Hansen, of the U.S. Forest Service, and Helen and Dan Winburn, Utah State Department of Fish and Game, during the fieldwork are sincerely appreciated.

Helpful criticism of the manuscript was provided by Prof. T. R. Walker and Prof. Z. M. Hunter, of the University of Colorado, as well as by many of my colleagues in the Geological Survey. Prof. J. W. Marr, of the Institute of Arctic and Alpine Ecology, University of Colorado, reviewed the section on vegetation. The physiographic diagram (pl. 3) was drawn by John Stacy. Oblique aerial photographs used as illustrations were taken by the Topographic Division, U.S. Geological Survey.

PREVIOUS PUBLICATIONS

Observations on the Quaternary geology of the region were first recorded by Powell (1875) on his trips down the Colorado River in 1869 and 1871. Peale (1877, p. 62) was the first to recognize that the mountains had been glaciated. He also noted the vast amounts of frost debris on them. Cross, in his unpublished field notes for 1905, made mention of the extensive "talus," and recorded the presence of moraines and extensive gravel benches older than the moraines. Hill (1913, p. 105) recognized that the ancient gravels on the mesas west of the mountains were probably glacial outwash that antedated the present canyons. He also recorded moraines in the mountains and noted the "rock streams or rock glaciers" among the high peaks. These latter features he believed to have originated as landslides in the manner postulated by Howe (1909) for similar forms in the San Juan Mountains. Hill also first described the conglomerate of Tertiary(?) age in Castle Valley.

Gould (1927) discussed the general geomorphology of the region, calling attention to the striking influence of the structure on erosional landforms and the difference in rate and character of erosion by streams in the several climate zones on the mountain slopes. He briefly described the cirques, U-shaped canyons, and moraines and suggested an extent of the valley glaciers approximately equivalent to that of the tills of the Beaver Basin formation of this report. He also observed many "rock glaciers," noting that some occurred in cirques, but that others, including the largest one, did not. Gould agreed with Howe (1909) that these features probably originated as landslides.

From 1930 to the present, relatively few observations of the Quaternary geology were made. Baker (1933) described thick gravel beds capping pediment surfaces at the south end of the mountains and obtained well data on the thickness of the alluvium in Spanish Valley. Dane (1935) noted an extensive alluvial fill in Fisher Valley north of the mountains and discussed its relation to a possible cycle of Quaternary alluviation along the Colorado River.

PRE-QUATERNARY STRATIGRAPHY

Rocks exposed in the area range in age from Pennsylvanian to Tertiary(?) (pl. 1 and table 1). The rocks of Paleozoic and Mesozoic age are all sedimentary, chiefly sandstone and shale, and are about 6,700 feet thick. The Tertiary rocks are chiefly intrusive stocks and laccoliths but include some conglomerate in Castle Valley. The intrusive igneous rocks are mostly of diorite porphyry, with some small bodies of monzonite, syenite porphyry, and various alkalic varieties. Volcanic vent breccias are locally associated with the intrusive rocks, especially in the North Mountain group (Hunt, 1958). The sedimentary rocks have been described in detail by Baker (1933), Dane (1935), and Hunt (1958).

STRUCTURE

The structure between the Colorado River and the La Sal Mountains consists of a series of broad parallel folds trending northwest (fig. 2). The Castle Creek and the Spanish Valley anticlines of Baker (1933) are broken by normal faults along which grabens have dropped to form the two major valleys (figs. 3, 4).

The folds generally dip less than 10°. The Navajo sandstone, the Entrada sandstone, and the Salt Wash member of the Morrison formation form a steplike succession of plateaus that rise southeastward from the Colorado River. Near the La Sal Mountains, however, the bedrock dips radially outward from the mountains at angles of 10° to 15°.

The mountains form three broad structural domes, around which the sedimentary rocks are steeply upturned (Hunt, 1958). Each dome consists of a central stock surrounded by several intrusive bodies—chiefly laccoliths, but locally phacoliths and sill-like masses—which extend into the surrounding sedimentary rocks. Most of the intrusive rocks are in sandstones of Triassic and Jurassic age, though a few penetrate the Mancos shale.

In southeastern Castle Valley, a body of conglomerate of Tertiary(?) age is chiefly composed of material from the intrusives of the North Mountain group. The mass has a basin-shaped structure unrelated to the regional folds and is upended against the intrusives. Hunt (1958) believes this structure resulted from lateral migration of salt of the Paradox member of the Hermosa formation from beneath Castle Valley at some time after the emplacement of the laccoliths.

GENERAL PHYSIOGRAPHY

The La Sal Mountains are broadly similar in physiographic aspects to other laccolithic mountains of the Colorado Plateau: the Blue (Abajo) Mountains, the Henry Mountains, the Carrizo Mountains, and Navajo Mountain. They rise approximately 6,500 feet above the plateau level and comprise three groups of peaks, called the North, Middle, and South Mountain groups (fig. 5). The highest peak, Mount Peale, in the Middle Mountain group, has an altitude of 12,721 feet. The surrounding plateau is dissected by a maze of canyons; the largest, that of the Colorado River, is more than 2,000 feet deep in places.

PHYSIOGRAPHIC SUBDIVISIONS

The region may be divided into six physiographic subdivisions: igneous mountains, hogbacks, plateaus, cuestas, pediments, and canyons (pl. 3). The dominant land form of each subdivision is chiefly the product of late Tertiary and early or middle Pleistocene erosion, controlled principally by the structure and relative competency of bedrock.

Superimposed on the dominant land forms are a great variety of secondary forms that differ at different altitudes—from the summits of the mountains to the Colorado River. These are mainly the product of late Pleistocene erosion and deposition.

IGNEOUS MOUNTAINS

The three mountain groups which make up the La Sal Mountains are underlain largely by resistant igneous rocks, and the shape of the laccolithic intrusions is reflected in considerable detail by the form of individual peaks. The North and South Mountain groups are

TABLE 1.—*Pre-Quaternary stratigraphy of the region of the La Sal Mountains*

System	Series	Group	Formation	Member	Thickness (in feet)	Description of rocks
Tertiary			Conglomerate in Castle Valley		1000+	Conglomerate of boulders, pebbles, and cobbles of diorite, monzonite, syenite porphyry, and red, brown, and gray sandstone. Competent.
			—Unconformity— Intrusive rocks of the La Sal Mountains —Unconformity—			Igneous rocks, mostly diorite, monzonite, and syenite porphyry, which intrude older sedimentary rocks as stocks, laccoliths, and dikes. Competent.
Cretaceous	Upper Cretaceous		Mancos shale		410–800+	Lead-gray marine shale. Incompetent.
				Ferron sandstone member		Buff thin-bedded sandstone and sandy shale, 60 feet thick. Incompetent.
						Lead-gray marine shale. Incompetent.
			Dakota sandstone		50–120	Sandstone, shale, siltstone, and coal. Sandstone is competent.
	Lower Cretaceous		—Unconformity— Burro Canyon formation		125	Sandstone, conglomeratic sandstone, conglomerate with pebbles of quartzite, and varicolored chert, silicified wood and vertebrate bones, limestone, and variegated shale. Mostly competent.
Jurassic	Upper Jurassic		Morrison formation	Brushy Basin shale member	350–400	Variegated red, green, and purple shale; some thin lenticular sandstone beds. Incompetent.
				Salt Wash sandstone member	300+	Gray and white, conglomeratic, cross-bedded and thick-bedded sandstone, locally carnotite-bearing; some interbedded thin shale. Competent.
		San Rafael group	—Unconformity— Summerville formation		0–50	Red thin-bedded sandstone and shale; some gray limestone with large chert concretions. Incompetent.
			Entrada sandstone		275–360	Red, orange, and white, massive, cross-bedded and thick-bedded sandstone. Competent.
	Upper and Middle Jurassic		Carmel formation		0–25	Red sandstone and mudstone. Incompetent.
Jurassic and Jurassic (?)	Lower Jurassic and Lower Jurassic (?)	Glen Canyon group	—Unconformity— Navajo sandstone		300+	Buff, gray, and white, massive, cross-bedded and thick-bedded, fine-grained sandstone. Competent.
Jurassic(?)	Lower Jurassic(?)		Kayenta formation		250±	Lavender, gray, and white, irregularly bedded sandstone, red sandy shale, limestone and shale-pebble conglomerate. Incompetent.
Triassic	Upper Triassic		Wingate sandstone		275–350	Reddish-buff, massive, horizontally thick-bedded and cross-bedded, fine-grained quartz sandstone. Competent.
			Chinle formation	Unnamed member	200–300+	Irregularly bedded, buff to red sandstone, red siltstone, limestone and mud-pellet conglomerate. Incompetent.
				Shinarump member	0–50	Light-brown to gray sandstone and pebble conglomerate containing fresh-water invertebrates, silicified wood, vertebrate bones, and buried soil horizons. Competent.
	Middle(?) and Lower Triassic		—Unconformity— Moenkopi formation		500±	Brown, thin-bedded, micaceous shale; ripple-marked, gray and brown thin-bedded sandstone and arkosic grit. Incompetent.
Permian			Cutler		1000±	Chocolate-brown and red sandy shale, maroon and pinkish-gray arkose and conglomerate of rounded pebbles of metamorphic and igneous rocks; some orange-red sandstone. Competent.
Carboniferous: Permian(?) and Pennsylvanian			Rico formation		200?	Buff, red, and purple arkosic sandstone and conglomerate with several thin beds of marine limestone. Competent.
Carboniferous: Pennsylvanian			Hermosa formation	Unnamed member	1500±	Gray and blue-gray interbedded limestone, sandstone, and shale. Incompetent.
				Paradox member	?	Gray sandy shale and sandstone, gray limestone, black shale, gypsum, and rock salt. Incompetent, plastic.
Precambrian			—Unconformity—			Granite, granite gneiss, biotite and hornblende schists. Not exposed.

elongated parallel to grabens in the sedimentary rocks; the Middle Mountain group is roughly circular in outline.

The summit uplands have convex slopes and rounded divides. Bedrock, though near the surface, is commonly covered by a blocky residual or colluvial mantle.

The mountains are sculptured by numerous small cirques, some forming large cirque-complexes, locally known as basins. Within the cirques are several generations of moraines or rock glaciers, the deposits of latest Pleistocene and Recent glacial advances. At the base of cirque headwalls are talus cones, most now inactive. The headwalls are deeply incised either by ragged talus chutes and chimneys, cut into frost-rubble slopes at their summits, or by glacially polished couloirs. Some, however, are so completely covered by talus or solifluction mantle that little bedrock remains exposed.

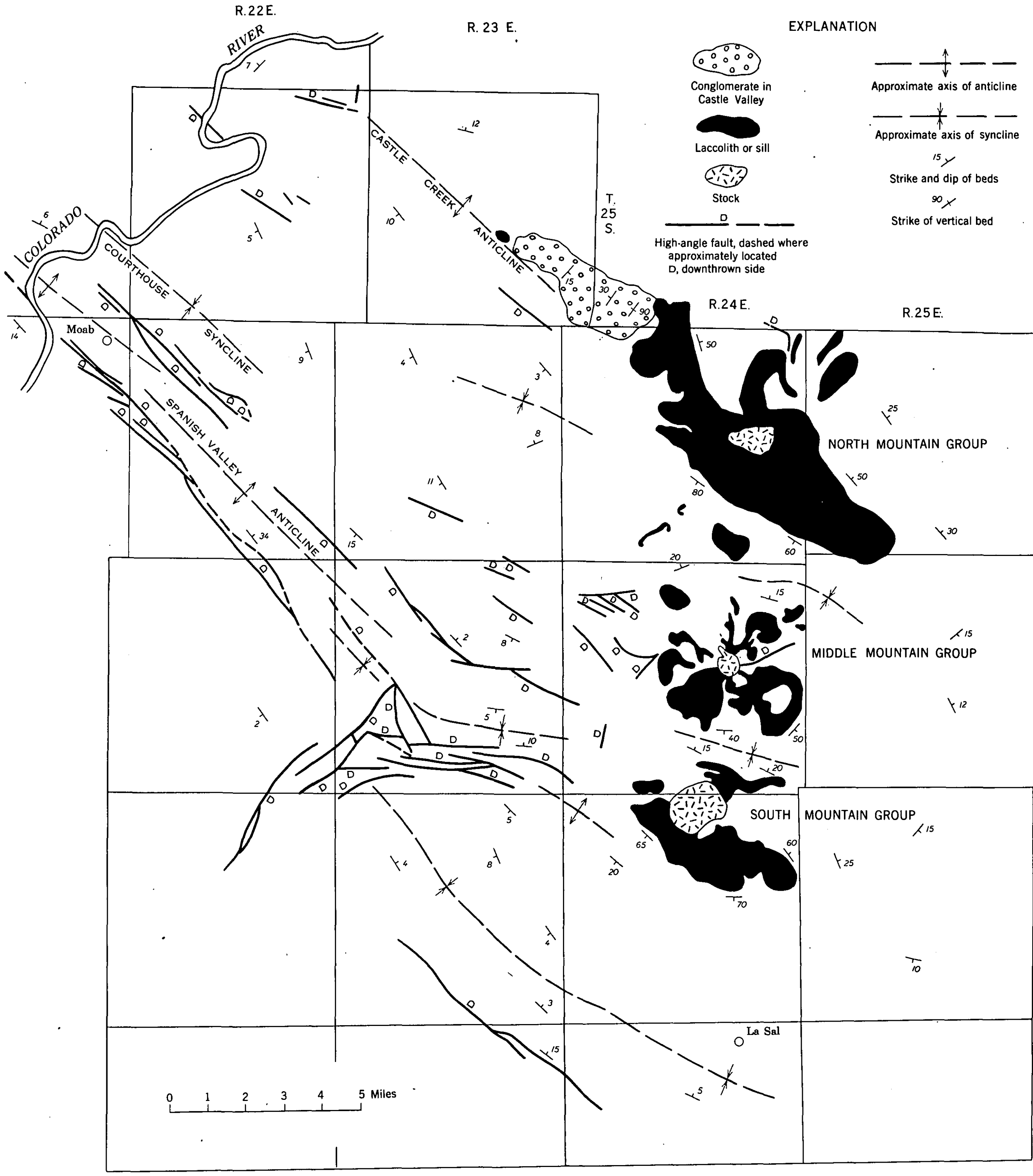


FIGURE 2.—Generalized map of the geologic structure in the vicinity of the La Sal Mountains (compiled after Baker, 1933, and Hunt, 1958).

Unglaciated mountain slopes between the cirques are extremely steep—many as steep as 40°—owing largely to the steep dip of the underlying rocks. Outcrops are scarce, however, for frost rubble or solifluction debris mantles the slopes to depths as great as about 20 feet.

Many youthful, steep-walled valleys penetrate the igneous mountains. Most are glaciated, but a few on South Mountain are not. Glaciation, however, has not greatly modified them, and only a few are deeply enough scoured to be typically U-shaped. Till mantles their floors and slopes, and lateral and end moraines are well preserved. The lowest end moraines tend to lie at or just beyond the mountain front.

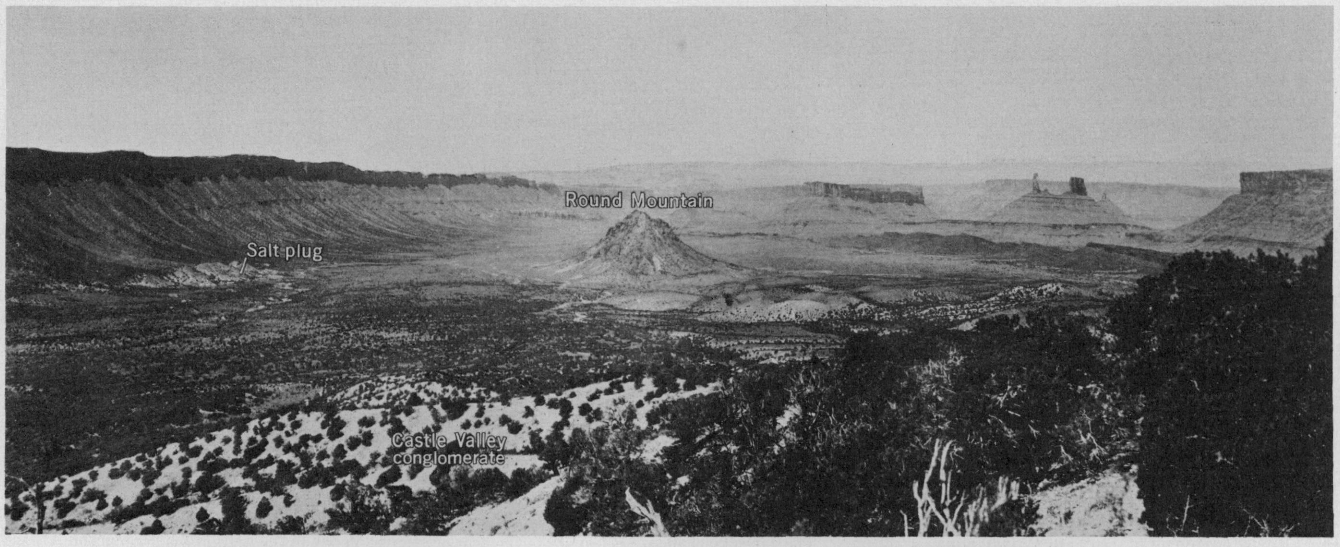


FIGURE 3.—Castle Valley from Harpole Mesa. Castle Valley is a broad anticline whose crest has collapsed along faults to form a graben. Round Mountain is a small laccolith intruded into the floor of the graben. The rocks in the foreground are part of a conglomerate of Tertiary(?) age which was deposited in the graben after intrusion of the stocks and laccoliths of the La Sal Mountains. The conglomerate has since been folded as a result of further collapse of the graben due to migration of salt from beneath into the border faults to form plugs like that along the left side of the valley.

FIGURE 4.—An aerial view of Spanish Valley. Spanish Valley occupies a graben, downfaulted along the crest of a broad anticlinal arch. Pre-Wisconsin alluvial gravel (*Qhal*) of the Harpole Mesa formation caps Johnsons Up-on-top and trends across the canyon of Mill Creek. The valley floor is a compound alluvial fill of Wisconsin and Recent age.

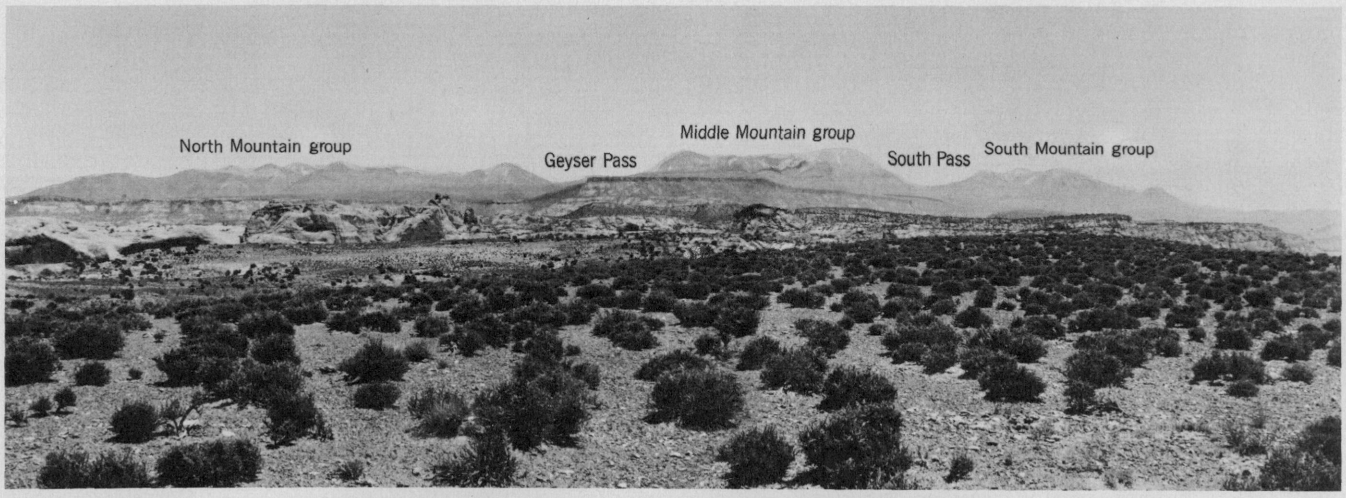


FIGURE 5.—The La Sal Mountains from the west. View of the North, Middle, and South Mountain groups across the plateaus from Johnsons Up-on-top, which is capped by a remnant of the oldest alluvial gravel in the area. The deposits lie about 850 feet above the floor of Spanish Valley to the right of the photograph.

The valley heads tend to be wider and more extensive in the stocks than elsewhere, particularly in the Middle Mountain group. The explanation for this is not obvious, but the greater erosion may be related to the closely spaced joint systems and hydrothermal alteration of the stocks.

HOGBACKS

Each mountain group is surrounded by steep hogbacks of resistant sandstone of Triassic and Jurassic age and separated from one another by a broad synclinal saddle underlain by weak shale of Cretaceous age. The outer slopes of the hogbacks are mostly mantled by frost rubble or solifluction debris, and the inner slopes by talus. Bedrock exposures are abundant only along the crests and in transverse canyons.

The synclinal swales between the mountain groups are mantled with till; some are very deeply weathered and lack morainal topography.

PLATEAUS

West of the mountains, four broad steplike plateaus or mesas extend toward the Colorado River. They are underlain successively by the resistant Burro Canyon formation, the Salt Wash member of the Morrison formation, the Entrada sandstone, and the Navajo sandstone. Near the mountains they slope westward as steeply as 500 feet per mile; near the Colorado River their surfaces undulate parallel to the broad folds in the underlying bedrock.

The two plateaus nearest the mountains are covered by extensive deposits of deeply weathered till and associated outwash. The two outer plateaus are irregularly mantled by eolian sand and silt, some in small active dunes. The bedrock rims of the plateaus, especially those underlain by the Navajo sandstone, have been delicately eroded into monuments and pedestal rocks.

CUESTAS

East and south of the mountains are two cuestas whose dip slopes are supported by the Salt Wash member of the Morrison formation and the Burro Canyon formation. Like the plateaus, these cuestas are mantled by deeply weathered till or outwash near the mountains. Farther away they become barren rock slopes covered only by a veneer of residual debris or by small irregular deposits of eolian sand and silt.

PEDIMENTS

Southwest and northeast of the mountains are a sequence of dissected pediments of probable early and middle Pleistocene age. These surfaces cut across the underlying bedrock structures on gradients ranging from 1,000 feet per mile in their upper parts to 400 feet per mile in their lower parts. They are capped by thick deposits of gravel that grade into deeply weathered till near major canyon reentrants. Eolian sand and silt irregularly mantles the gravel on the lower slopes of the pediments.

CANYONS

Many of the valleys in the mountains terminate on the slopes of the adjacent plateaus. Most, however, extend—as narrow, sinuous, steep-walled canyons—radially from the mountains across the plateaus, cuestas, and pediments to the Dolores or Colorado Rivers. The canyons have steep gradients; many are more than 1,000 feet deep. Most major streams appear to be consequent on structural slopes, though some, such as East Coyote Wash and West Coyote Creek, are subsequent in synclinal troughs; others follow weak formations or faults for short distances; and still others, such as Negro Bill Canyon, cross the underlying structure in such a way as to suggest that they may have been superposed from a late Tertiary or early Pleistocene gravel cover.

The canyons are relatively free of surficial deposits. Near the mountains, their walls tend to be mantled by solifluction debris, talus, or landslides—all virtually inactive at present. Downstream, they are typically barren, locally alcoved cliffs along whose bases are small talus heaps.

Castle Valley and Spanish Valley are broad, steep-walled, relatively flat-floored troughs. In the upper parts of both, alluvial terraces merge downstream to form a single depositional surface; in the lower parts, the terraces diverge again as distinct entities. The margins of both troughs are bordered by extensive alluvial fans that head in talus along the cliffed walls.

The canyon of the Colorado River along the northwest margin of the area is a series of incised meanders that cross major fold axes and the graben underlying Spanish Valley in a manner suggesting superposition from ancestral cover rocks now stripped, as proposed by Emmons (1897) and Davis (1901).

Along the river are distinct but discontinuous alluvial terraces. Talus and small alluvial fans border the canyon walls.

CLIMATE

The region of the La Sal Mountains embraces a considerable climatic range. In general, the plateaus and canyons bordering the Colorado River are arid. The mean annual precipitation is less than 10 inches, and the mean annual temperture is between 50° and 60° F. The fringing foothills and plateaus are semiarid. Mean annual precipitation is between 10 and 15 inches, and mean annual temperture is between 40° and 50° F. The mountain areas are subhumid. Mean annual precipitation is between 15 and 25 inches, and locally it is as much as 30 inches. Mean annual temperature in the mountain areas is estimated to range from about 30° to 40°F.

The United States Weather Bureau maintains recording stations at Moab (altitude, 4,000 feet) and La Sal (altitude, 7,000 feet). Precipitation and temperature records from these stations are summarized in tables 2, 3, and 4.

PRECIPITATION

Precipitation records (tables 2 and 3) show wide variations in monthly and annual precipitation. The range in average monthly precipitation, however, amounts to less than an inch. Though there is no well defined rainy season, an interval of maximum precipitation occurs from July to October, and a secondary maximum of shorter duration takes place in March or April. June has normally the least precipitation, and dry intervals commonly begin in early May and end in late July.

The wide variation in precipitation reflects the fact that most rain falls as scattered local thunderstorms, which, on relatively barren ground, cause damaging flash floods. The road along the canyon of the Colorado River, north of Moab, may be closed for short intervals by flood debris mudflows from secondary canyons several times a year. In the mountains, most heavy rains are absorbed by the vegetation-covered surficial deposits; only very locally are slopes being gullied.

Hail frequently accompanies thunderstorms in the mountains. Regional storms commonly produce partly cloudy to overcast conditions on the plateau, and heavy overcast with intermittent showers or occasional rains of 1 to 2 days duration in the mountains.

Widespread snows fall between September and March, beginning in the mountain areas. The greatest accumulations are in December and January at Moab and in the foothills, but the snows continue into March in the mountains. The average annual snowfall at Moab is about 6 inches, and at La Sal it is about 58 inches. It increases rapidly with altitude and in the high basins of the moutains amounts to more than 10 feet. In general, snow at Moab melts in a few hours or at most in a few days, but it may last for weeks at La Sal, and into April or early May in the foothills. In the mountains, snowbanks in sheltered places last throughout the summer.

TEMPERATURE

The region has marked extremes of temperature (table 4), both diurnal and seasonal. Diurnal changes at Moab, and generally in the lower parts of the area, are commonly about 40°F and are occasionally over 60°. Summer daytime maxima are commonly over 100°F, the maximum recorded being 113°. Corresponding night minima may be as low as 40°F. Winter daytime maxima are as high as 60°F but may remain below freezing for several days at a time. Night temperatures are commonly below freezing and may fall to zero levels. The average monthly temperature at Moab ranges from 28.9°F in January to 79.5° in July.

591960 O—62——2

TABLE 2.—*Monthly, annual, and average precipitation, in inches, at Moab, Grand County*

[Elevation, 4,000 feet. Years of record, 57]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1889	------	------	------	------	------	------	------	0. 45	0. 02	0. 80	0. 33	2. 83	------
1890	0. 58	1. 28	0. 68	0. 29	Tr.	Tr.	0. 10	. 61	. 26	. 18	1. 05	. 55	5. 58
1891	. 60	. 57	. 40	. 11	0. 39	0. 07	1. 35	. 43	2. 41	Tr.	. 00	. 82	7. 15
1892	1. 20	. 71	1. 41	. 60	. 93	Tr.	. 37	. 20	Tr.	. 41	. 37	. 41	6. 61
1893	. 72	. 43	. 53	. 34	. 76	Tr.	. 89	1. 11	1. 28	. 05	1. 46	. 77	8. 34
1894	. 33	. 60	. 74	. 58	. 68	. 24	. 02	. 66	. 69	. 79	. 00	1. 23	6. 56
1895	. 64	. 89	1. 57	. 02	. 35	. 12	1. 14	. 11	. 36	. 47	1. 38	. 35	7. 40
1896	. 45	Tr.	. 18	. 11	. 17	. 03	. 66	. 51	5. 97	. 83	. 30	. 32	9. 53
1897	1. 22	2. 12	2. 43	. 72	. 38	. 14	. 80	. 60	1. 46	2. 52	. 48	1. 82	14. 69
1898	. 77	. 13	. 44	. 25	1. 58	. 16	. 17	. 35	. 00	Tr.	. 25	. 22	4. 32
1899	. 48	. 15	. 57	. 37	. 39	. 76	. 55	2. 04	. 03	1. 06	. 11	1. 13	7. 64
1900	. 42	. 12	. 04	1. 03	. 03	. 26	. 02	. 37	1. 43	. 22	. 53	. 00	4. 47
1901	. 32	. 58	. 56	. 75	1. 19	. 20	. 39	1. 47	Tr.	1. 41	. 02	. 28	7. 17
1902	. 40	. 49	. 91	. 40	. 84	. 43	. 30	. 53	1. 26	Tr.	1. 94	. 40	7. 90
1903	. 12	. 90	. 91	. 69	. 84	. 70	. 84	. 03	1. 27	. 28	. 00	. 05	6. 63
1904	. 15	. 41	. 90	. 08	1. 41	. 26	. 37	. 97	. 25	. 63	. 00	. 29	5. 72
1905	1. 90	1. 35	1. 51	. 66	2. 28	. 00	. 53	. 15	1. 95	. 12	1. 55	. 11	12. 11
1906	. 57	. 21	1. 88	1. 72	1. 79	Tr.	. 77	. 58	2. 08	. 23	1. 75	1. 57	13. 15
1907	1. 18	. 56	. 92	. 36	1. 40	. 37	. 81	1. 73	. 60	. 68	. 27	. 39	9. 27
1908	. 34	1. 71	. 95	. 36	. 41	. 20	1. 54	1. 29	. 73	2. 49	. 86	1. 49	12. 37
1909	. 94	. 70	. 56	1. 16	. 09	Tr.	. 50	. 84	1. 17	. 18	1. 56	2. 02	9. 72
1910	. 71	. 03	1. 31	. 03	Tr.	1. 32	. 25	. 78	. 84	1. 17	1. 12	1. 50	9. 06
1911	1. 00	1. 11	. 82	. 47	Tr.	. 60	1. 22	. 75	1. 72	2. 60	. 21	. 60	11. 10
1912	. 16	. 26	2. 76	. 65	. 98	. 83	. 90	. 30	. 08	2. 95	. 65	. 35	10. 87
1913	. 94	1. 49	. 10	. 35	. 19	. 40	. 37	. 29	1. 78	. 05	1. 19	1. 90	9. 05
1914	1. 32	. 57	. 44	1. 07	1. 23	1. 20	2. 00	. 77	. 31	1. 66	. 02	. 31	10. 90
1915	2. 31	1. 02	. 25	1. 02	1. 93	. 17	. 51	. 43	1. 08	. 14	. 88	5. 75	15. 49
1916	3. 52	. 45	1. 17	. 45	. 90	. 00	. 53	. 90	. 73	4. 20	. 05	. 33	13. 23
1917	1. 66	. 10	. 54	2. 78	1. 47	. 17	. 55	. 03	. 78	. 02	. 13	. 06	8. 29
1918	1. 65	. 22	1. 38	1. 04	. 11	1. 15	6. 63	. 56	. 72	. 75	. 65	1. 10	15. 96
1919	. 00	. 50	. 50	. 20	. 26	Tr.	1. 03	. 55	. 87	. 51	1. 48	. 23	6. 13
1920	. 59	1. 46	. 54	1. 30	. 08	. 44	. 26	. 79	. 32	1. 73	. 40	. 44	8. 35
1921	. 68	. 26	. 37	1. 45	1. 35	. 37	1. 12	2. 33	. 00	. 51	. 65	1. 59	10. 68
1922	. 61	. 70	. 51	1. 04	. 57	. 33	. 21	1. 16	. 03	. 01	. 69	. 52	6. 38
1923	. 17	. 15	1. 30	1. 00	. 45	Tr.	. 79	. 37	1. 07	. 61	1. 15	. 80	7. 86
1924	. 45	. 45	1. 26	. 73	. 69	Tr.	1. 16	. 53	1. 30	1. 03	. 20	3. 16	10. 96
1925	. 51	. 60	. 32	. 52	. 03	. 85	1. 10	1. 86	1. 76	2. 13	. 46	. 46	10. 60
1926	. 02	. 65	1. 27	1. 09	2. 22	. 00	1. 33	. 37	. 90	. 56	. 14	2. 17	10. 72
1927	1. 01	2. 50	2. 01	. 33	. 06	2. 35	1. 30	. 66	3. 55	1. 14	. 44	. 61	15. 96
1928	. 11	Tr.	. 69	. 12	1. 56	. 23	1. 39	. 80	. 12	3. 50	1. 98	. 31	10. 81
1929	. 74	1. 09	1. 09	1. 14	1. 85	. 10	. 78	. 83	1. 73	. 14	. 73	. 08	10. 30
1930	2. 55	. 99	. 41	1. 81	. 25	. 53	1. 14	1. 17	1. 36	. 36	. 60	. 00	11. 17
1931	Tr.	. 01	. 42	. 02	. 32	. 38	. 30	. 20	1. 66	1. 00	. 85	. 71	5. 87
1932	. 21	. 53	. 68	. 99	. 10	. 70	1. 67	1. 99	. 20	. 10	. 00	. 92	8. 09
1933	. 44	Tr.	. 49	. 79	1. 21	Tr.	2. 15	1. 49	. 05	. 60	. 87	. 38	8. 60
1934	. 65	1. 49	. 00	. 41	1. 26	. 04	. 17	1. 37	. 44	. 00	1. 09	. 86	7. 78
1935	1. 24	1. 20	1. 11	1. 04	. 58	. 00	. 50	. 64	. 41	. 12	. 30	1. 17	8. 31
1936	. 16	1. 07	. 52	. 27	. 21	. 25	1. 17	1. 62	. 43	. 36	. 10	1. 40	7. 56
1937	. 25	. 52	1. 42	. 05	. 19	. 39	2. 35	1. 65	. 83	. 48	. 41	. 75	9. 29
1938	. 42	. 93	1. 01	. 39	1. 00	. 56	. 00	. 84	. 91	. 97	. 18	. 97	8. 18
1939	. 78	. 61	1. 48	. 00	. 73	. 02	. 00	1. 59	3. 13	1. 42	. 44	. 03	10. 23
1940	. 82	1. 27	. 41	1. 06	. 03	. 38	1. 17	. 44	3. 46	2. 18	1. 05	1. 26	13. 53
1941	. 62	. 91	1. 64	1. 76	. 82	1. 22	. 44	. 77	1. 12	4. 40	1. 35	. 37	15. 42
1942	. 32	1. 02	. 60	1. 53	1. 17	. 00	. 11	. 37	. 64	. 79	. 08	. 12	6. 75
1943	. 50	. 24	1. 38	. 22	. 55	1. 16	. 56	. 94	. 61	. 87	. 95	. 57	8. 55
1944	46	. 69	. 53	1. 86	. 45	1. 33	. 00	. 02	. 00	. 52	. 78	. 22	6. 86
1945	. 68	. 42	1. 30	. 69	. 13	1. 50	. 82	. 88	. 00	1. 98	. 25	. 84	9. 49
Avg	0. 74	0. 70	0. 88	0. 72	0. 73	0. 41	0. 86	0. 81	1. 02	0. 96	0. 64	0. 85	9. 37

TABLE 3.—*Monthly, annual, and average precipitation, in inches, at La Sal, San Juan County*

[Elevation, 7,000 feet. Years of record, 45]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1901	------	------	------	0. 61	1. 68	0. 23	0. 81	2. 55	------	------	0. 01	0. 43	------
1902	1. 52	1. 57	1. 87	. 05	. 60	. 03	. 06	. 09	2. 03	Tr.	1. 37	. 45	9. 64
1903	. 60	. 90	1. 01	. 61	1. 05	1. 68	. 72	. 31	1. 00	0. 10	. 00	. 00	7. 98
1904	------	------	------	------	------	. 19	. 82	2. 95	. 66	1. 04	. 00	. 80	------
1905	. 99	2. 20	1. 94	1. 83	2. 17	. 04	. 95	Tr.	1. 48	. 16	1. 80	. 39	13. 95
1906	1. 13	------	------	------	------	. 00	1. 37	1. 38	1. 83	. 48	1. 41	. 21	------
1907	. 60	. 45	------	------	------	------	------	------	------	------	------	------	------
1908	------	------	------	1. 14	. 91	. 30	. 62	2. 26	1. 20	2. 24	------	1. 55	------
1909	1. 19	1. 14	. 22	. 73	Tr.	. 06	2. 70	1. 87	1. 40	. 37	1. 28	2. 20	13. 16
1910	. 53	. 58	. 59	. 37	. 10	1. 18	1. 50	. 63	. 82	1. 03	1. 37	1. 33	10. 03
1911	------	------	. 49	. 70	Tr.	1. 29	2. 40	------	------	2. 39	. 05	. 30	------
1912	. 10	. 85	. 76	. 79	. 02	1. 86	1. 58	. 25	. 08	1. 91	2. 00	. 56	10. 76
1913	. 08	. 79	. 20	Tr.	Tr.	. 10	. 62	. 84	2. 02	. 26	1. 38	1. 30	7. 59
1914	2. 47	. 42	. 27	. 46	1. 32	1. 57	1. 90	1. 08	. 34	2. 00	. 03	. 50	12. 36
1915	. 51	2. 00	. 25	1. 13	2. 18	. 88	. 84	. 25	1. 70	. 00	. 90	1. 72	12. 36
1916	1. 78	. 77	1. 28	. 94	. 54	Tr.	2. 32	2. 12	. 56	2. 47	. 09	. 59	13. 46
1917	. 82	. 24	------	------	------	. 00	------	1. 54	1. 21	. 00	. 00	. 00	------
1918	2. 00	. 69	. 76	1. 38	. 05	1. 40	1. 20	. 02	1. 65	. 85	. 85	. 90	11. 75
1919	. 00	. 90	. 35	. 35	1. 43	. 00	2. 75	2. 15	1. 19	. 79	1. 30	. 85	12. 06
1920	1. 13	2. 11	. 90	1. 00	1. 00	. 75	. 90	1. 70	1. 10	1. 20	. 74	1. 10	13. 63
1921	. 93	. 87	. 28	1. 55	1. 52	1. 64	1. 96	3. 22	. 58	1. 91	. 94	1. 79	17. 19
1922	. 55	. 25	. 64	. 30	. 20	------	------	------	. 07	------	. 33	1. 45	------
1923	. 45	. 07	. 15	. 70	. 80	. 07	1. 16	1. 96	1. 30	. 50	1. 89	. 70	9. 75
1924	. 01	. 07	. 47	. 70	. 40	. 00	1. 90	. 77	1. 15	1. 35	. 20	5. 25	12. 27
1925	. 50	. 28	. 50	. 70	Tr.	1. 36	2. 20	1. 44	2. 85	3. 85	. 15	1. 70	15. 53
1926	Tr.	. 83	. 45	2. 86	3. 26	. 00	. 70	. 50	1. 08	1. 72	Tr.	2. 00	13. 40
1927	. 50	3. 20	2. 00	. 30	. 30	3. 06	. 70	2. 60	4. 64	2. 50	. 31	. 70	20. 81
1928	------	------	------	------	1. 44	. 49	. 20	. 55	. 12	3. 75	4. 40	------	------
1929	------	------	------	------	------	------	------	------	1. 90	. 46	. 01	. 15	------
1930	1. 85	. 29	1. 00	2. 28	. 28	. 22	2. 31	1. 04	. 96	. 40	. 80	. 07	11. 50
1931	. 27	. 81	. 86	. 65	. 25	. 43	1. 47	. 35	1. 48	1. 87	1. 18	. 73	10. 35
1932	. 22	1. 00	. 98	1. 20	. 44	. 41	2. 70	3. 98	1. 69	. 30	. 01	. 97	13. 90
1933	. 82	. 06	. 60	. 75	1. 58	. 03	4. 20	. 31	. 89	1. 22	1. 43	. 36	12. 25
1934	. 83	1. 45	. 03	. 39	. 86	. 15	. 72	1. 33	. 59	. 22	1. 20	. 59	8. 36
1935	1. 92	1. 35	. 99	1. 53	1. 95	. 01	1. 57	1. 48	1. 72	. 82	. 29	. 87	14. 50
1936	. 14	1. 22	. 36	. 16	. 34	1. 27	3. 46	3. 30	. 70	1. 29	. 13	1. 55	13. 92
1937	. 59	1. 06	1. 70	Tr.	. 46	. 33	2. 83	2. 40	1. 15	. 50	. 40	. 20	11. 62
1938	. 48	. 30	------	------	. 04	. 57	. 87	------	------	------	------	1. 10	------
1939	2. 02	. 59	. 96	Tr.	. 04	. 00	. 85	. 03	3. 66	1. 25	. 00	. 08	9. 48
1940	1. 41	1. 44	------	------	------	------	------	. 70	3. 63	1. 52	. 91	1. 88	------
1941	1. 36	1. 37	1. 66	2. 86	1. 47	2. 20	. 54	2. 95	3. 08	5. 34	. 48	1. 46	24. 77
1942	. 83	1. 30	1. 28	2. 47	. 26	. 00	. 75	1. 31	. 73	. 82	. 55	. 10	10. 40
1943	1. 63	. 53	1. 11	. 46	. 62	1. 20	1. 23	2. 36	. 49	. 78	. 55	1. 17	12. 13
1944	. 73	1. 69	. 61	2. 27	. 63	2. 07	. 57	. 81	. 02	. 35	2. 08	. 98	12. 81
1945	1. 09	. 68	. 78	1. 70	. 40	. 98	2. 12	2. 45	. 12	1. 91	. 12	1. 80	14. 15
Avg	0. 88	0. 95	0. 81	1. 24	0. 78	0. 68	1. 47	1. 45	1. 34	1. 27	0. 78	1. 00	12. 66

In the foothills and mountains diurnal changes are somewhat less than at Moab, and maximum and minimum temperatures become progressively lower at increasing altitudes. Summer daytime maxima in the mountains are rarely over 70°F, and night minima are rarely below freezing. Winter daytime maxima in December and January rarely get above freezing, and night minima are commonly subzero. Seasonal fluctuations are about as wide as at Moab, but maxima and minima are lower.

WINDS

Regional winds are mostly gentle from the southwest; high winds occur in winter, and gusts precede thunderstorms in summer. Wind frequency suffices to maintain active dunes in Spanish Valley and on the plateaus east of Moab. In Spanish Valley, silt is carried several hundred feet into the air at times, and local residents report that the snow in the high mountain basins is colored red from silt accumulations in some years. The direction of ground winds is greatly influenced by the

TABLE 4.—*Temperatures at Moab (56-year record) and La Sal (39-year record)* (°F)

Station	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Average monthly and annual													
Moab	28.9	36.7	46.4	53.3	64.2	72.4	79.5	75.9	67.1	54.6	41.3	31.1	54.3
La Sal	24.5	28.6	32.6	44.5	53.1	62.2	68.9	67.4	59.0	48.3	36.3	26.1	45.6
Highest monthly													
Moab	65	78	88	97	102	108	113	107	103	90	82	68	
La Sal	60	64	70	76	85	94	100	93	86	89	81	67	
Lowest monthly													
Moab	−24	−13	8	15	27	36	43	41	29	18	4	−18	
La Sal	−22	−27	−3	5	19	25	34	37	19	0	−1	−22	

local topography, especially along the Colorado River and in the troughs of Spanish Valley and Castle Valley. In the mountains, canyon winds are reversed daily, owing to diurnal temperature changes.

VEGETATION

The differences in climate in the 8,700 feet of relief between the Colorado River and the highest peaks have induced a distinct zonal differentiation of the vegetation broadly ranged with altitude (pl. 4 and fig. 6). Two major ecologic divisions are represented: the Rocky Mountain Forest Complex and the Great Basin Desert ecologic formation.

ROCKY MOUNTAIN FOREST COMPLEX

The Rocky Mountain Forest Complex in the La Sal Mountains, though generally similar to that along the flanks of the Rocky Mountains from Alberta to northern Mexico, differs in certain important aspects. It includes four zones, each characterized by a distinctive vegetation.

- Alpine zone
  - Alpine tundra associations
- Subalpine zone
  - Engelmann's spruce-subalpine fir climax
- Montane zone
  - Aspen and meadow subclimax
- Foothills zone
  - Scrub oak-mountain-mahogany climax
  - Ponderosa pine climax
  - Pinyon-juniper climax

ALPINE ZONE

The alpine zone lies above a timberline which ranges in altitude from about 11,000 feet on north-facing slopes to about 11,500 feet on south-facing slopes. As mapped (pl. 4) the zone includes areas of barren rock, rock glaciers, and frost-rubble deposits. It is characterized by several tundra associations composed of cushion plants, cinquefoils (*Sieversia turbinata*, *Potentilla* spp.), and various sedges (*Carex* spp.) and grasses. The absence of species of *Dryas* and *Salix*, common to the alpine tundra of the Rocky Mountains of Colorado and northward, reflects the more arid environment of the La Sal Mountains. The abundance of grasses in the communities suggests that a mature climax is being approached. The alpine zone is wholly on Brown Podzolic soils.

SUBALPINE ZONE

The subalpine zone, whose upper limit is timberline, lies mostly between 9,500 and 11,500 feet. On some south-facing slopes, especially on South Mountain, this zone appears to be relict on the sandstone hogbacks bordering the mountain as low as 8,800 feet. On the east and west flanks of the mountains the zone is mostly above 9,500 feet but on the north flank of the North Mountain group, it extends down to 8,000 in a few places.

The zone is characterized by dense stands of Engelmann's spruce (*Picea engelmanni*) and less abundant subalpine fir (*Abies lasiocarpa*). Some Douglas-fir (*Pseudotsuga taxifolia*) is interspersed in the lower part of the zone.

The subalpine zone is mostly devoloped on Brown Podzolic soils, but it extends nearly halfway down through the range of Brown Forest soils in a few places.

Timberline appears to be currently advancing upslope. Clumps of young spruce, displaying a vigorous and unimpeded growth, appear to be encroaching over the tundra above the upper limit of the forest proper. Most of these spruce trees, especially those on south-facing slopes, are erect and uniformly developed, and in only a few exposed places are they flagged, twisted, or otherwise influenced by wind. Some of the trees have

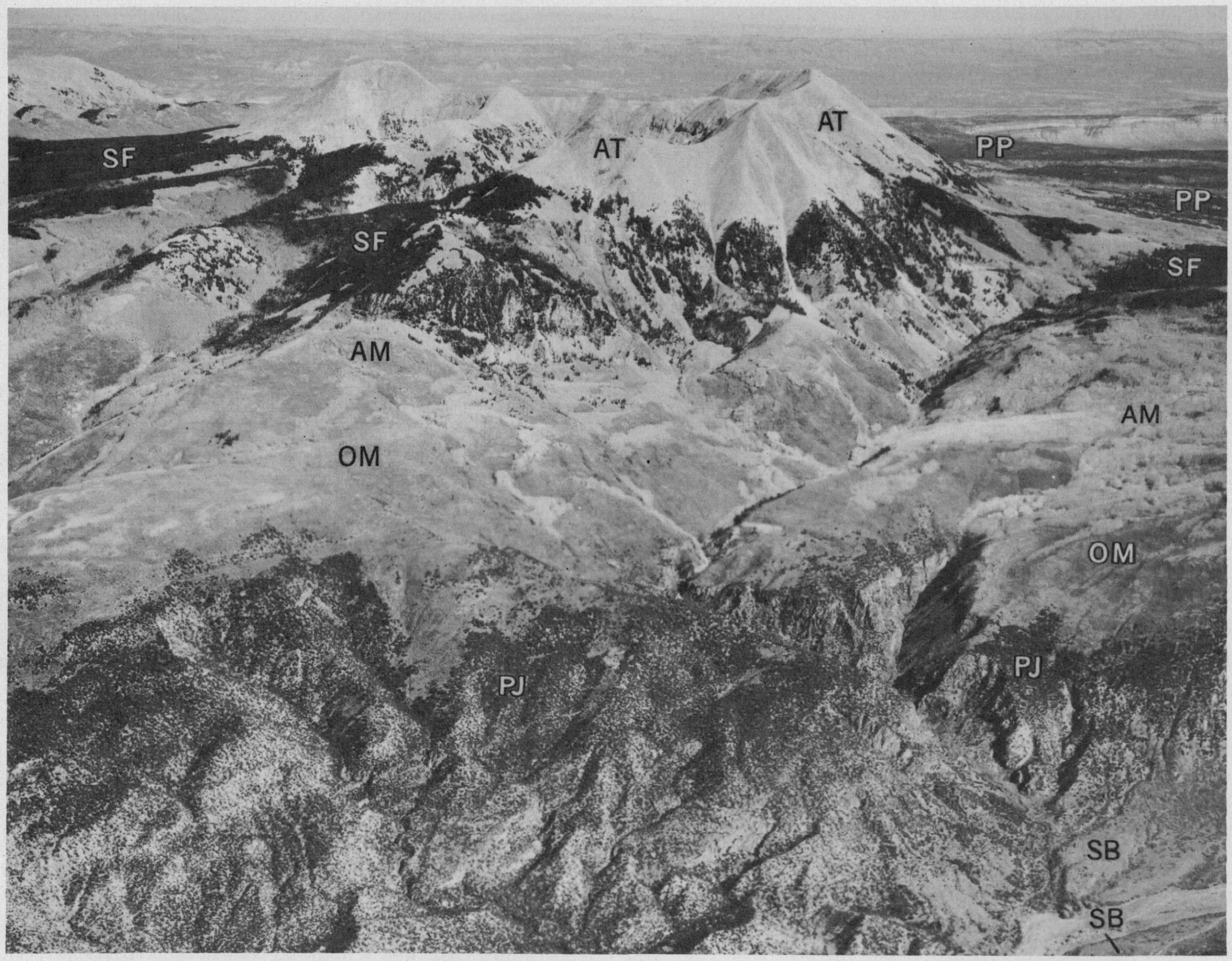


FIGURE 6.—Aerial view showing distribution of vegetation zones on the west side of the Middle Mountain group, La Sal Mountains, Utah. *AT*, Alpine tundra association; *SF*, Spruce-fir climax, including some Douglas fir climax; *AM*, Aspen and meadow subclimax; *PP*, Ponderosa pine climax, on east slope only; *OM*, Scrub oak-mountain mahogany climax; *PJ*, Pinyon-juniper climax; *SB*, Sagebrush association.

taken hold on shallow active frost-rubble deposits, and here individual trees tend to have considerably thinner growth rings on their upslope side than on their downslope side, owing to the pressure of the rubble moving against them. Even these clumps, however, appear to be spreading gradually.

The current apparent advance of timberline is from a position that was in turn preceded by one somewhat higher than at present. This possible higher timberline is suggested by local stands of dead, gnarled and twisted relatively large trees that extend farther upslope from the present forest than the upper limit of new growth. Most of the dead clumps do not appear to be parent to the new growth, though some new growth may contain dead or dying material. The older trees appear to have been killed by climatic factors, for no evidence suggests destruction by fire or other agent. The age of these trees has not been established, but they may antedate the most recent local glacial advance. Subsequent regression of timberline is inferred to have taken place during the most recent glacial maximum, following which the new growth appears to be a readvance.

MONTANE ZONE

The montane zone is not as clearly expressed by a climax vegetation here as it is in the Rocky Mountains of Colorado by Douglas-fir and ponderosa pine. The ponderosa pine climax, the lower part of the montane zone in the Rocky Mountains, is here lower and in a special environment within the scrub oak-mountain-mahogany climax of the foothills zone. It will therefore be discussed as part of that zone.

In the normal position of the montane zone, below the spruce-fir of the subalpine zone, is a belt of aspen (*Populus tremuloides*) and meadows that completely encircles the mountains. It lies mostly between 8,000 and 10,000 feet. The actual boundaries are highly sensitive to exposure, moisture accumulation, and other environmental factors, so that tongues of aspen extend as high as 10,800 feet on some south-facing slopes, especially on the east and west flanks of the mountains, and as low as 6,500 feet on some north-facing slopes. Small, isolated patches of spruce and fir are common high in the zone, and tongues of scrub oak and ponderosa pine, related to lower zones, extend up into the aspen to altitudes as high as 9,500 feet on certain south-facing slopes.

The aspen and meadow subclimax consists of fairly thick stands of aspen separated by open meadows of tall grasses and many kinds of herbs; the grasses and herbs also extend as a thick undergrowth through the aspen groves. This subclimax is developed mostly on Brown Podzolic soils but extends through the range of Brown Forest soils locally, and in a few places it penetrates the range of Brown soils.

In the Rocky Mountains, aspen is normally subclimax to spruce-fir or Douglas-fir climax stands, following fire, lumbering, or other catastrophic destruction of the climax forest. Some small areas of aspen in the La Sal Mountains are undoubtedly in this category. Few areas, however, represent growth following fires, for there have been very few forest fires, and none of great size, in historic time in the La Sal Mountains. And lumbering has been restricted to small areas.

The breadth and distinctiveness of the zone of aspen and meadow, as well as its continuity around the mountains, suggest that it is climatically controlled. The stratigraphic record implies that climatic zones shifted considerably in altitude during the late Pleistocene and Recent and may have affected the vegetation zones nearly as much as timberline. The transitional zone between any two adjacent vegetation climaxes would therefore be the locus of alternations of migration and regression. Hence the zone of fast-growing aspen and meadow may represent a persistent subclimax vegetation between two competing climaxes. The aspen zone currently appears to be following the spruce-fir climax upslope and losing ground below to ponderosa pine or scrub oak and mountain-mahogany, under increasingly warm and dry conditions.

FOOTHILLS ZONE

The foothills zone in the La Sal Mountains includes four distinct climax communities. The uppermost is a scrub oak-mountain-mahogany climax which lies mostly between 6,500 and 9,000 feet on north-facing slopes and between 7,500 and 9,500 feet on south-facing slopes. The vegetation consists of patchy but relatively pure stands of scrub oak (*Quercus gambelli* and other spp.) and intervening areas of mountain-mahogany (*Cercocarpus* spp.) and other brush. At higher altitudes subsidiary squawbush (*Rhus trilobata*), buckbrush (*Ceanothus greggi*), chokecherry (*Prunus virginiana*), and serviceberry (*Amelanchier utahensis*) occur among grasses and flowering herbs. Chokecherry is abundant at intermediate altitudes, and sagebrush (*Artemisia tridentata*) and sparse grass are present at lower altitudes. This climax is mostly developed on Brown Forest soils, but in a few places it extends as much as 1,000 feet up into the range of Brown Podzolic soils and halfway down through the range of Brown soils.

A second climax community in the foothills zone is ponderosa pine, which forms a belt along the north, east, and southeast slopes of the mountains, either within the altitude range of the oak-mountain-mahogany climax or between that and a lower pinyon-juniper climax.

Ponderosa pine is absent on the west and south sides of the mountains except for a few lone trees along streams. The extensive stands to the north and east are relatively pure except near their margins, where the trees are widely spaced, and oak, aspen, or grass intervene.

The ponderosa climax is restricted to sandstone areas covered only by a thin mantle of relatively sandy material in the areas of somewhat higher rainfall on the east side of the mountains. It is developed about equally on Brown and Brown Forest soils, but it invades the lower limit of Brown Podzolic soils in a few places. It does not extend downward through the range of Brown soils. These conditions, together with the fact that ponderosa lies within or below the altitude range of the oak-mountain-mahogany climax, whereas in the Rocky Mountains it lies above that climax, suggest that the present distribution of ponderosa pine in the La Sal Mountains may be relict from a more widespread stand during a past and somewhat cooler and wetter interval. Presumably, it is preserved on areas of sandstone because these rocks contain more moisture than adjacent areas of shale.

A pinyon-juniper climax is developed on the plateaus, mesas, alluvial fans, gravel-covered pediments, and terraces from an altitude of about 7,500 feet to an altitude of about 5,500 feet. The upper limit of the climax extends to about 8,500 feet on some south-facing slopes, and the lower limit extends to about 5,000 feet on some north-facing slopes. It is mostly developed on Sierozem and Brown soils, but it extends as much as halfway up through the range of Brown Forest soils in a few places.

In its upper range, the climax consists of both mixed and relatively pure stands of juniper (*Juniper utahensis*, *J. scopulorum* et spp.) and pinyon (*Pinus edulis* et spp.).

In its lower range it consists mostly of juniper. Openings between the trees support sparse grass, herbs, and low shrubs, including Mormon tea (*Ephedra* sp.), sagebrush (*Artemisia tridentata*), blackbrush (*Coleogyne* sp.), squawbush (*Rhus trilobata*), and blackbrush (*Ceanothus greggi*). Yucca (*Yucca* spp.), and various cacti, such as pricklypear (*Opuntia* sp.), are also abundant.

The pinyon-juniper climax is widespread throughout the Colorado Plateaus. Its position below the oak-mountain-mahogany climax in the La Sal Mountains, the Blue (Abajo) Mountains, the Henry Mountains, and elsewhere is in striking contrast to its position above the oak-mountain-mahogany climax along the east slope of the Southern Rocky Mountains south of Denver. J. W. Marr (written communication, 1954) has indicated that although juniper commonly lies above oak with respect to altitude near Denver it actually occupies a more xerophytic environment. The zonation with altitude expressed in the La Sal Mountains is therefore probably normal.

Within the altitude range of the pinyon-juniper climax, and locally penetrating the range of the ponderosa pine and scrub oak-mountain-mahogany climaxes, are small areas in which a sagebrush-grass association appears to be the climax vegetation.These areas are mostly on eolian sand, between 7,000 and 9,200 feet on the south and west slopes of the mountains. South of the mountains they merge downward with the widespread sagebrush-grass climax of the Great Basin Desert ecologic formation.

This higher sagebrush-grass climax consists of the same dominant species (*Artemisia tridentata*) as that at lower altitudes. It differs from the lower climax in its greater degree of restriction to eolian deposits, in persisting under conditions of somewhat greater rainfall and cooler climate, and in being developed largely on Brown Forest soils rather than on Brown and Sierozem soils as is the lower climax. Further, the higher climax lacks the variants associated with saline soils or with local small areas of unusual aridity that are common to that at lower altitudes. It also contains a greater abundance of shrubs and herbs than the lower. These differences suggest that the sagebrush association at higher altitudes is ecologically part of the foothills zone rather than an extension of the Great Basin Desert ecologic formation. An "Upper sagebrush-grass" climax similar to this, but more sharply demarcated from the pinyon-juniper climax with respect to altitude, has been described by Billings (1951) from the Basin Ranges of Nevada.

GREAT BASIN DESERT ECOLOGIC FORMATION

The Great Basin Desert ecologic formation consists primarily of a sagebrush-grass association that is confined for the most part between altitudes of 4,000 and 7,000 feet. It is developed wholly on Sierozem and Brown soils. This association is widespread in Spanish Valley and Castle Valley (pl. 4); where it occurs on terraces underlain by alluvial gravel or sand, locally veneered with eolian sand. The sagebrush (*Artemisia tridentata*) is commonly 12 to 24 inches high, but close to intermittent water courses it may attain a height of 6 to 10 feet. The intervening grass is sparse.

Included in the sagebrush-grass association below 7,000 feet are several vegetational variants. In the lower part of the valley of Pack Creek, upstream from Spanish Valley, and on the pediment gravels east of Round Mountain in Castle Valley, sagebrush is replaced by blackbrush (*Coleogyne ramosissima*), which survives the locally more arid environment of these and a few other localities.

Along the flood plains of intermittent streams below 7,000 feet, where water is available at relatively shallow depths, and beside long-used irrigation ditches are occasional cottonwoods (*Populus fremontii*) and an abundance of willows (*Salix* spp.). Where water has been removed from streambeds by irrigation for several years, the cottonwoods appear to be dying, as they do locally along Castle Creek. In Spanish Valley, from the vicinity of Moab as far south as the Summerville Ranch, Russian olive (*Elaeagnus angustifolia* L.), an introduced shrub, has become established along the flood plain of Pack Creek in relatively thick stands.

On low terraces, where the alluvium contains abundant gypsum or other salines, sagebrush is locally replaced by stands of greasewood (*Sarcobatus vermiculatus*), or in a slightly more arid environment by shadscale (*Atriplex confertifolia*).

Along the Colorado River, gravel terraces support a sagebrush-grass association and small stands of scrub oak (*Quercus gambelli*). The sandy flood plain of the river is mostly covered by willow (*Salix* sp.?), and there are some areas of tamarisk (*Tamarix gallica*). Poison ivy (*Rhus toxicodendron*) is present along the river upstream from Moab. The talus-covered lower slopes of the canyon walls support sparse grass, herbs, and a few juniper trees.

QUATERNARY STRATIGRAPHY

The Quaternary stratigraphy of the La Sal Mountains is the geologic record of physical processes that were controlled for the most part by the same cyclical changes in climate responsible for world-wide Quaternary glacial and interglacial intervals. During each glacial-interglacial cycle, the extent to which any specific process dominated the region varied considerably

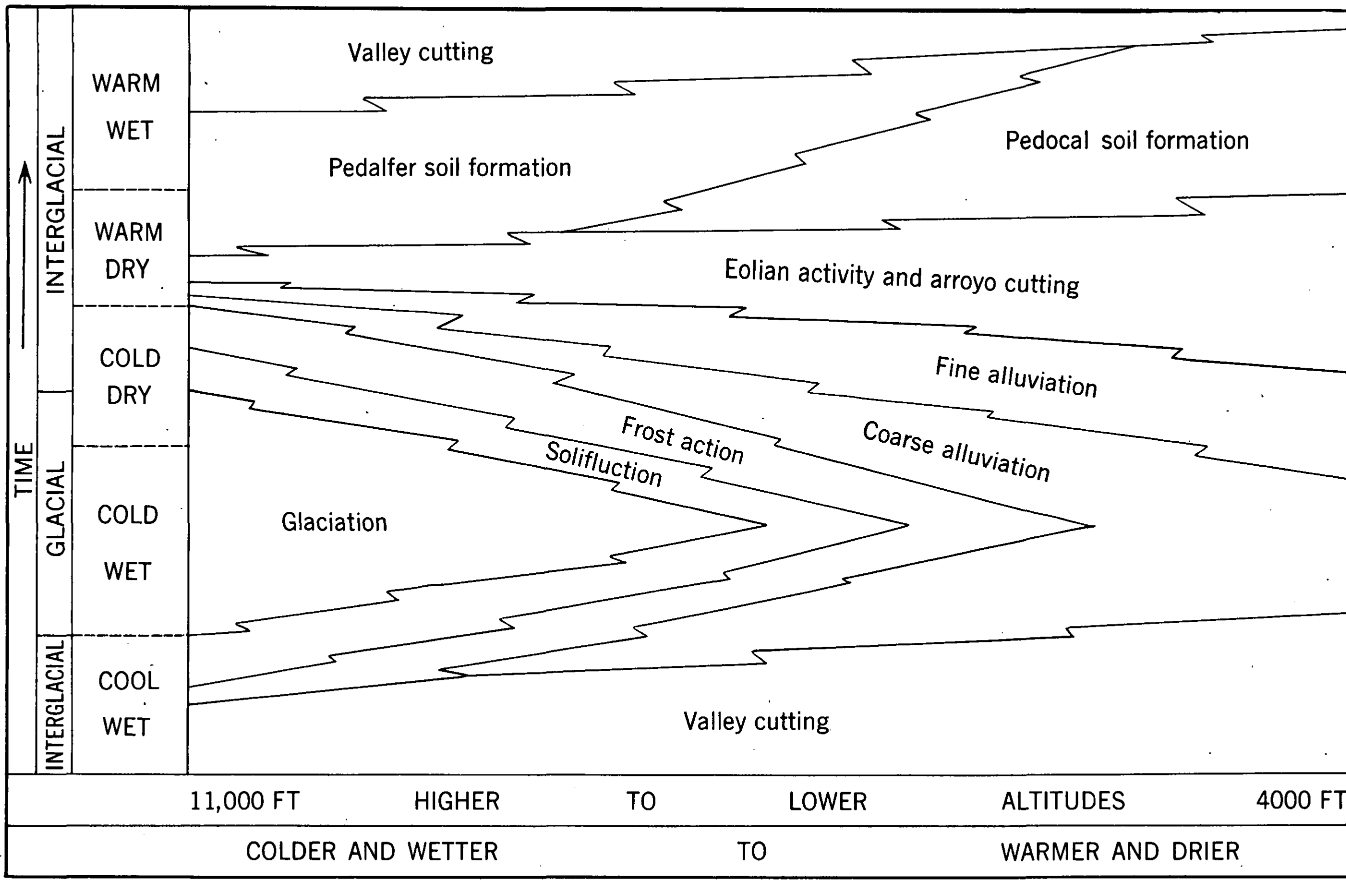


FIGURE 7.—Schematic illustration of the range in process domination with altitude, time, and inferred climate during a typical glacial-interglacial cycle in the La Sal Mountains, Utah.

with altitude, both at any given time and with the passage of time (fig. 7). In general, however, each cycle consisted of four episodes. Starting with glaciation, these were (1) widespread sedimentation in the valleys, accompanied by glacial and colluvial erosion of the uplands; (2) eolian activity and arroyo cutting; (3) soil formation under conditions of essential slope stability; and (4) valley deepening and valley widening by stream erosion.

An unusually complete Quaternary stratigraphic record of at least nine glacial-interglacial cycles is preserved. The deposits are continuous and well preserved in individual valleys, but over the area as a whole they are both discontinuous and thin. Their stratigraphic succession has been determined from several kinds of evidence (fig. 8): (1) physiographic criteria, especially the relation of depositional surfaces to erosional surfaces; (2) physical relations of deposits; (3) disconformities; and (4) soil profiles. The soil profiles possess recognizable characteristics and such specific geologic relations that they became significant markers of particular geologic horizons.

ROCK-STRATIGRAPHIC TERMINOLOGY

In North America, deposits of the Quaternary system have, by custom, received somewhat different treatment in regard to rock-stratigraphic terminology from those of older systems. Terms such as "group," "formation," and "member" have rarely been applied to glacial, fluvioglacial, or colluvial deposits, though they have been used for marine deposits and locally for alluvial, lacustrine, and eolian deposits.

In this report, a formation is treated broadly as a lithogenetic unit which is also a mappable unit. More specifically, a formation includes those subaerial deposits of diverse specific origin which have mutually gradational or interfingering relations, and which are related in the same way to identifiable, immediately younger and older formations. The base of a formation is commonly a disconformity; the top is marked by a distinctive soil whose highest stratigraphic position is the top of that formation.

Members, as identified in this report, are similar to formations, except that they are only locally identifiable within formations and the soil at their surface is not necessarily distinctive of a particular member.

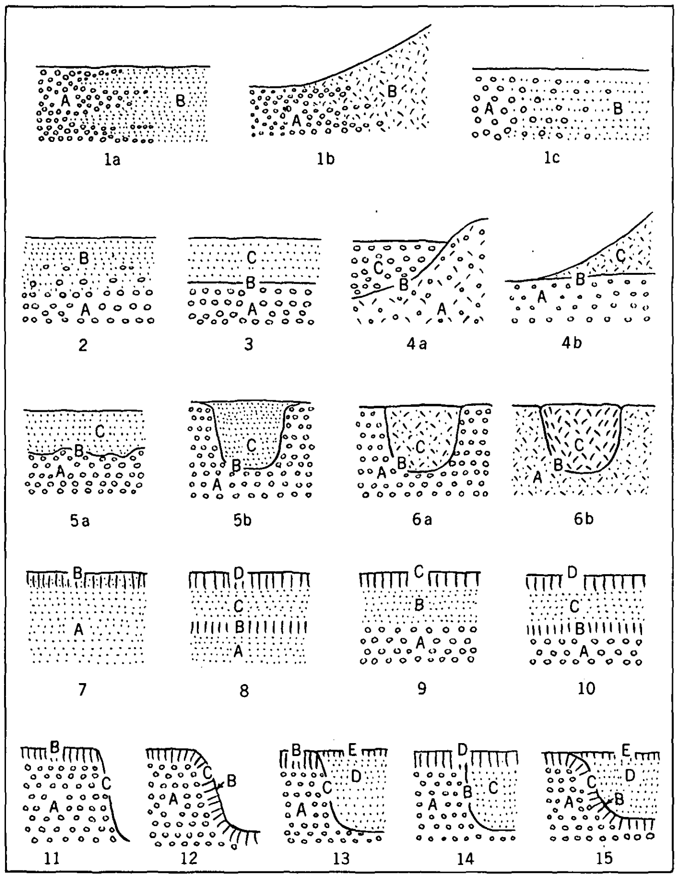


Figure 8.—Diagram showing kinds of physical relations of deposits, disconformities, and soils on which the Quaternary stratigraphy of the La Sal Mountains is based.

1. Contemporaneous deposition of two kinds of deposits. (*a*) Interfingering and lensing of different facies. (*b*) Interfingering and lensing of different facies with difference in slope of depositional surface. (*c*) Lateral gradation of facies.
2. Continuous deposition with vertical change in facies.
3. Conformable deposition of different facies. Deposit A is older than depositional surface B, which is older than deposit C.
4. Overlap. Deposit A is older than depositional surface B, which is older than deposit C. (*a*) Sloping surface on overlapped deposit. (*b*) Sloping surface on overlapping deposit.
5. Erosion followed by deposition. Deposit A is older than disconformity B, which is older than deposit C. (*a*) Extent of disconformity is unknown. (*b*) Extent of disconformity can be observed.
6. Erosion and penecontemporaneous deposition. Deposit A is older than disconformity B. (*a*) Deposit C is till which was formed during same glaciation in which disconformity B was cut or scoured by the ice. (*b*) Deposit C is solifluction debris or block rubble. Disconformity B was formed at same time as deposit C.
7. Deposition followed by stability. Deposit A is older than soil B.
8. Stability interrupting deposition of similar deposits. Deposit A is older than soil B, which is older than deposit C and soil D.
9. Stability following continuous deposition of dissimilar deposits. Deposit A is older than deposit B, which is older than soil C.
10. Stability separating deposition of dissimilar deposits. Deposit A is older than soil B, which is older than deposit C and soil D.
11. Deposition followed by stability and later erosion. Deposit A is older than soil B, which is older than erosion surface C.
12. Deposition followed by erosion and later stability. Deposit A is older than erosion surface B, which is older than soil C.
13. Deposition followed by stability and later erosion before renewed deposition and final stability. Deposit A is older than soil B, which is older than disconformity C. Disconformity C is, in turn, older than deposit D, which is older than soil E. Soil E has not megascopically affected soil B.
14. Deposition followed by erosion, further deposition, and final stability. Deposit A is older than disconformity B, which is older than deposit C and soil D.
15. Deposition followed by erosion and stability before renewed deposition and final stability. Deposit A is older than disconformity B, which is older than soil C. Soil C is older than deposit D, which is older than soil profile E. Soil E has not megascopically affected soil C.

The deposits of diverse specific origin contained in a formation or member include such units as till, solifluction manlte, alluvial gravel, talus, or eolian deposits. As these units are discontinuous and locally of slight extent, they are most readily described informally as facies of specific formations or members.

Subdivision of the Quaternary deposits in the La Sal Mountains into formations, members, and facies, together with the local names assigned to them is shown in figure 9. A brief descriptive glossary of the several kinds of facies as distinguished in the area is given below.

Till.—An unsorted and unsized mixture of rock and mineral debris, having morainal features or containing glacially striated, soled, or faceted fragments.

Alluvial gravel.—A deposit of bedded, round to subround gravel, cobbles, and boulders in a clean sandy matrix. It includes both outwash and nonglacial stream deposits, and is commonly composed in large measure of diorite.

Alluvial sand and silt.—A deposit of sand or silt, or mixture thereof, that is evenly bedded or displays alluvial channel-and-fill crossbedding.

Alluvial-fan gravel.—A bedded deposit of locally derived, poorly sorted, angular to subangular rock debris in a sandy, silty, clayey matrix. The deposit may also contain layers of similar, but unsorted and nonbedded, material of possible mudflow origin. Most of the debris is sandstone, but some derived from older gravel may contain an appreciable amount of diorite and much rounded material.

Slope-wash mantle.—A crudely bedded sheet of sorted to unsorted and commonly angular rock and mineral debris that may locally display a shallow surficial rill pattern.

Solifluction mantle.—A sheetlike deposit of unsorted rock and mineral debris that tends to be abruptly separated from subjacent mantle and displays surface features or internal involuted structures suggesting downslope movement by slow flowage.

Frost rubble.—A deposit of angular blocky or irregularly shaped rock fragments of pebble or larger size that contains little or no matrix, has no cliff or prominent ledge at its head, and is primarily the product of frost action.

- *Rubble sheet:* An irregularly shaped deposit of frost rubble that is thin in relation to its legth and breadth.
- *Rubble lobe:* A tabular sloping mass of frost rubble whose extent across the slope is greater than that down the slope, and whose lower margin is arcuate downslope in plan and convex upward in profile.
- *Rubble stream:* A large tabular sloping mass of frost rubble whose extent down the slope is greater than that across the slope, and whose lower margin is arcuate downslope in plan and convex upward in profile.
- *Rubble rill:* A small, narrow tonguelike mass of frost rubble that extends irregularly down a slope.
- *Rubble festoon:* A narrow mass of frost rubble that extends as an irregular arc or series of arcs across a slope and commonly has a lobate lower margin.

These descriptive categories of frost rubble may be more specifically ascribed to (1) frost riving, or splitting of subjacent rock by frost action; (2) frost creep, or downslope movements of rubble as a result of freezing and thawing; (3) frost sorting, or the concentration of

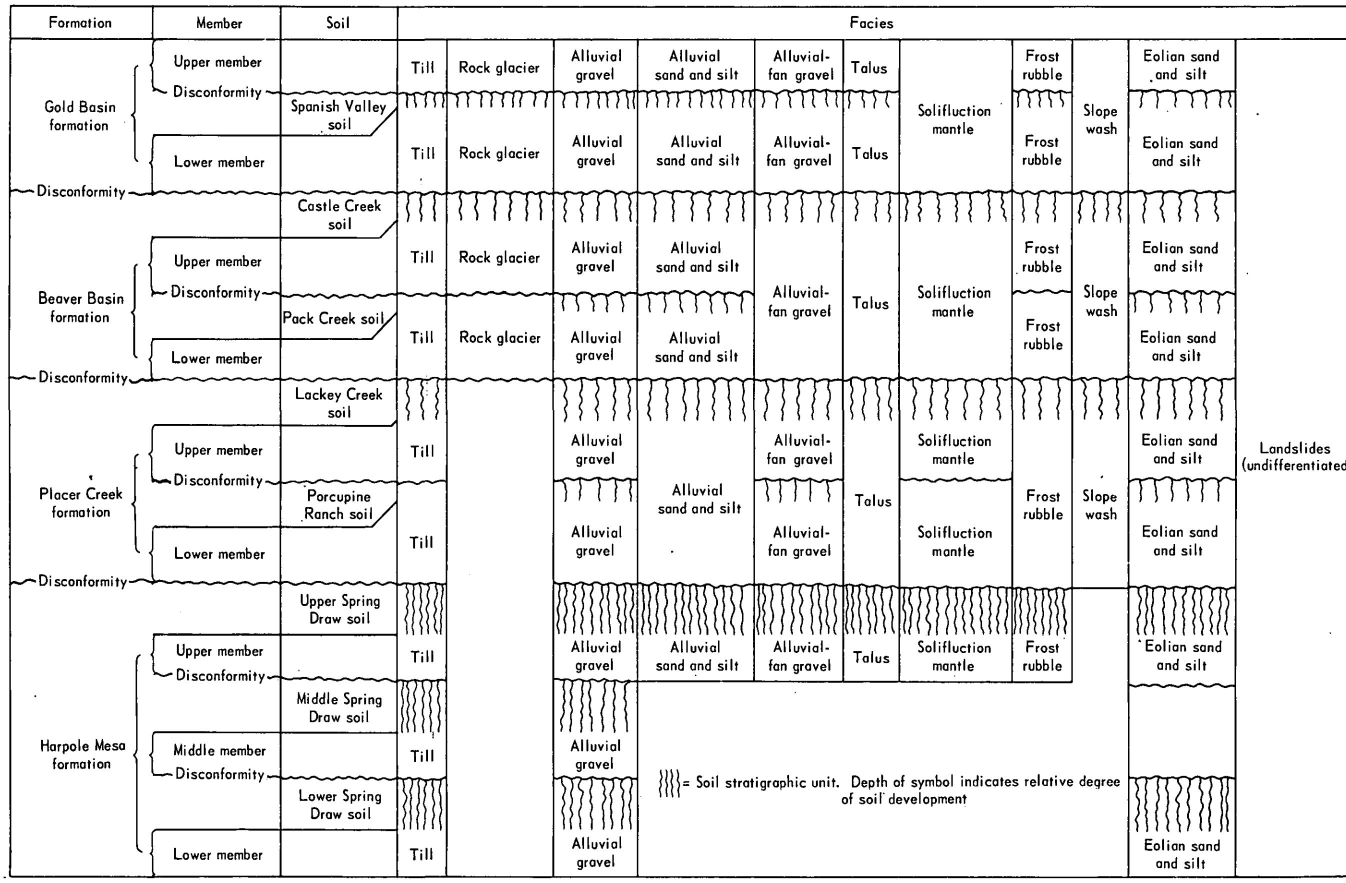


FIGURE 9.—Stratigraphic column of Quaternary deposits in the La Sal Mountains.

rubble at the surface of a subjacent deposit of mixed debris without significant net downslope displacement; and (4) frost lag, or the concentration of rubble at the surface of a deposit of mixed debris during downslope movement as a result of freezing and thawing, solifluction, and slope wash.

Talus.—A heap or sloping sheet of rubble or debris at the foot of a cliff, bluff, or series of ledges from which it is derived by piecemeal disintegration.

Protalus rampart: A ridge of rubble or debris that has accumulated piecemeal by rock-fall or debris-fall across a perennial snowbank, commonly at the foot of a talus.

Protalus lobe: A tonguelike or lobate mass of rubble or debris that is the product of creep or solifluction of the toe of a talus.

Rock glacier.—A tonguelike or lobate mass of rubble, locally with a core of till-like debris, that has surface features resembling some of those of a glacier.

Eolian sand and silt.—A deposit of sand or silt, or mixture thereof, that displays eolian crossbedding, dunal form, or other evidence of deposition by wind.

TIME-STRATIGRAPHIC TERMINOLOGY

The term "stage" has been widely used with special reference to subdivisions of the Pleistocene, but in a conflicting sense by different writers. By some, it has been used as a geologic-time term for major subdivisions of the Pleistocene epoch, in the manner recommended by the stratigraphic code (Ashley and others, 1933); by others, it has been used as a time-stratigraphic term in the sense adopted by the International Geological Congress (Renevier, 1901). This problem is ably stated in the report of the American Commission on Stratigraphic Nomenclature (1948, p. 372, Note 5), which recommended revision of the stratigraphic code to provide for recognition of the term "stage" as a time-stratigraphic unit, and of the term "age" as a geologic-time unit of classification. The commission (1952, p. 1634) has defined these terms with the recommendation that they apply to all parts of the geologic column, including the Quaternary.

SOILS

The term "soil," as used in this report, means soil profile or profile of weathering. A soil is recognized and defined on the basis of gross physical profile characteristics that are the product of chemical and physical changes induced in unconsolidated mantle or bedrock by exposure to the earth's surficial environment. A soil is therefore a layer of material formed parallel to the earth's surface that is both genetically distinct and younger than the one or more underlying rock units from which it is derived, but of which it is no longer a part. Its top is commonly the earth's surface or, where buried, a subaerial unconformity. However, soils locally grade upward into overlying deposits. The base of a soil is commonly a zone of gradation into underlying deposits, but in some it is a sharp contact.

A soil thus has many features common to a rock-stratigraphic unit. It differs from a rock unit in being formed primarily from underlying deposits, though some ingredients of a soil may be derived from other sources, and some rock units, such as a felsenmeer, may be of residual origin. Also, because a soil is defined on its weathering or pedologic characteristics, it commonly lacks the lithologic homogeneity that defines a rock unit. For example, a soil overlying several lithologically different rock units may have broadly the same weathering characteristics throughout, though the rock and mineral particles in it differ widely from the subjacent rock unit.

A soil is not an unconformity, for that term refers simply to a surface. Most unconformities are erosion surfaces buried beneath transported deposits (Lahee, 1941, p. 67; Pettijohn, 1949, p. 146). Less commonly, an unconformity is considered to be a surface of nondeposition or a surface between bedrock and its overlying residual products (Lahee, 1941, p. 69). In contrast, a soil is the material product of residual weathering. It may extend downward from, rest on, or be crosscut by an unconformity, and is commonly a criterion for recognizing or dating an unconformity; but it is a material, not a surface.

SOIL CLASSIFICATION

The soils recognized in the La Sal Mountains (pl. 2) are essentially equivalent to the great soil groups of soil science. However, certain profiles classed as Chestnut soils by the Soil Conservation Service of the U.S. Department of Agriculture are here included as the Brown soils, and certain other soils that may be Red Podzolic soils are included as Brown Podzolic soils. The following generalized descriptive definitions of the four soil groups recognized in the La Sal Mountains are modified for purposes of this report from the definitions given in the glossary of the Department of Agriculture, Yearbook of Agriculture, Soils and Men (1938, p. 1162–1180).

Brown Podzolic soil.—Soils characterized by a dark grayish-brown, acid, humus-mineral A horizon, partly leached of clay and sesquioxides; a very thin, pale gray A_2 subhorizon which is only locally developed; a brownish to yellowish-brown, acid B horizon of clay and sesquioxide accumulation grading down into parent material.

Brown Forest soil.—Soils characterized by a dark brownish, acid, humus-mineral A horizon, partly leached of clay and sesquioxides; a brownish, slightly acid B horizon of clay and sesquioxide accumulation; a pale, neutral to mildly alkaline Cca horizon of slight carbonate accumulation grading down into parent material.

Brown soil.—Soils characterized by a brownish, slightly acid to neutral, humus-mineral A horizon, partly leached of clay and sesquioxides; a brownish, slightly acid to mildly alkaline B horizon of clay and sesquioxide accumulation; a pale, alkaline Bca or Cca horizon of marked carbonate accumulation grading down into parent material.

Sierozem soil.—Soils characterized by a very thin, gray or grayish-brown, neutral to slightly alkaline, humus-mineral A horizon, partly leached of clay and sesquioxides; a thin Bca horizon of lighter colored alkaline material that in some places displays clay, sesquioxide, and carbonate accumulation; a pale, alkaline Cca horizon of marked and, in some places, well-cemented carbonate accumulation grading down into parent material.

DESCRIPTION OF SOIL PROFILES

The method of describing soil profiles in this report follows, as closely as possible, that recommended in the Soil Survey Manual of the U.S. Department of Agriculture (Soil Survey Staff, 1951).

IDENTIFICATION AND NOMENCLATURE OF SOIL HORIZONS

The following soil horizon designations are used in this report though not all occur in any one profile (fig. 10). The A horizon is characterized by accumulation of organic matter, a washing out of clay, and a leaching of carbonate and iron oxide. The A_2 subhorizon is differentiated only in podzolic soils under a spruce-fir forest. The B horizon is characterized by accumulation of clay and iron oxide and generally by leaching of carbonate. Soil structure is commonly most prominent in the B_2 subhorizon. The Bca subhorizon is an accumulation of calcium carbonate or calcium sulphate in the lower part of the B horizon; the Cca subhorizon represents similar accumulations in the C horizon.

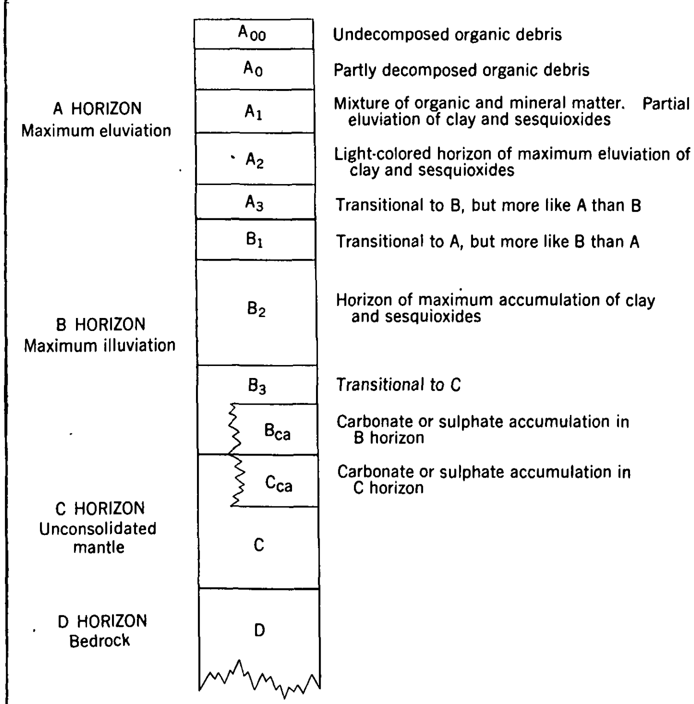


FIGURE 10.—Possible horizons in soil profiles.

These subhorizons are recognized in Brown Forest soils, Brown soils, and Sierozem soils. The C horizon is unconsolidated mantle, either residual or transported, below the soil. It may represent the parent material on which the soil profile is developed. Or, it may be overlain by other mantles that are transgressed by, and included in, upper horizons of the profile but are at the same time the major parent material of the profile. The D horizon is bedrock. Openings in the rock may, where the C horizon is lacking, contain accumulations of clay, sesquioxide, or calcium carbonate.

HORIZON BOUNDARIES

The boundaries between soil horizons are commonly gradational and somewhat overlapping. In buried soils, or relict soils that have undergone more than one cycle of soil profile development, secondary carbonate may have accumulated in the A horizon or in the upper part of the B horizon. Horizon boundaries are necessarily somewhat arbitrary.

Terms used to describe horizon boundaries are as follows:

Abrupt.—Ranges from a sharp contact to 1 inch in thickness.
Clear.—Ranges from 1 to 2½ inches in thickness.
Gradual.—Ranges from 2½ to 5 inches in thickness.
Diffuse.—More than 5 inches in thickness.

SOIL COLOR

Names of soil colors follow the usage of the U.S. Department of Agriculture and refer only to the dry soil. Color symbols are those of the Munsell system (Munsell Soil Color Charts, 1954).

SOIL TEXTURE

Descriptions of soil textures are based on field examination without mechanical analysis. Terms used to describe texture refer to the size-separation scale of the Department of Agriculture.

SOIL STRUCTURE

The structure of the soil profile, particularly of the B horizon, is one of its more diagnostic characteristics. The term "structure" in soil science refers to the aggregation of primary soil particles into secondary compound particles known as peds, whose shape, size, and distinctness range widely under different conditions of parent material and environment. Types and classes of soil structure are given in table 5.

Terms signifying grade of structure are as follows:

Structureless.—No observable aggregation.
Weak.—Poorly formed indistinct peds, which when disturbed break into a mixture of few entire peds, many broken peds, and much unaggregated material.
Moderate.—Well-formed, distinct, and moderately durable peds, which when disturbed break down into many distinct peds, some broken peds, and little unaggregated material.
Strong.—Well-formed, distinct, and durable peds, which resist displacement and break down into many entire peds, a few broken peds, and little unaggregated material.

TABLE 5.—*Types and classes of soil structure*

[After Soil Survey Staff, 1951, p. 228]

Class	Type (shape and arrangement of peds)						
	Platelike aggregates arranged in a horizontal plane	Prismlike aggregates with horizontal dimensions considerably less than vertical. Vertical faces well defined; vertices angular		Blocklike, polyhedral, or spheroidal aggregates, with three dimensions of the same order or magnitude			
				Plane or curved surfaces that are casts or molds of faces of adjacent peds		Plane or curved surfaces that have slight or no accommodation to faces of adjacent peds	
		Caps flat	Caps rounded	Faces flat vertices angular	Faces rounded and flat; many rounded vertices	Relatively nonporous peds	Porous peds
	Platy	Prismatic	Columnar	Angular-blocky	Subangular blocky	Granular	Crumb
Very fine or very thin.	Very thin platy; 1 mm.	Very fine prismatic; 10 mm.	Very fine columnar; 10 mm.	Very fine angular blocky; 5 mm.	Very fine subangular blocky; 5 mm.	Very fine granular; 1 mm.	Very fine crumb; 1 mm.
Fine or thin	Thin platy; 1 to 2 mm.	Fine prismatic; 10 to 20 mm.	Fine columnar; 10 to 20 mm.	Fine angular blocky; 5 to 10 mm.	Fine subangular blocky; 5 to 10 mm.	Fine granular; 1 to 2 mm.	Fine crumb; 1 to 2 mm.
Medium	Medium platy; 2 to 5 mm.	Medium prismatic; 20 to 50 mm.	Medium columnar; 20 to 50 mm.	Medium angular blocky; 10 to 20 mm.	Medium subangular blocky; 10 to 20 mm.	Medium granular; 2 to 5 mm.	Medium crumb; 2 to 5 mm.
Coarse or thick	Thick platy; 5 to 10 mm.	Coarse prismatic; 50 to 100 mm.	Coarse columnar; 50 to 100 mm.	Coarse angular blocky; 20 to 50 mm.	Coarse subangular blocky; 20 to 50 mm.	Coarse granular; 5 to 10 mm.	
Very coarse or very thick.	Very thick platy; >10 mm.	Very coarse prismatic; >100 mm.	Very coarse columnar; >100 mm.	Very coarse angular blocky; >50 mm.	Very coarse subangular blocky; >50 mm.	Very coarse granular; >10 mm.	

SOIL CONSISTENCE

Soil consistence includes those characteristics of a soil that express its degree of cohesion or adhesion and its resistance to deformation or rupture.

General terms used to describe consistence are as follows:

Consistence when wet.—Moisture at field capacity or higher.
- *Stickiness or adhesion.*—Measured by pressing between thumb and fingers.
  - *Nonsticky.*—No adhesion.
  - *Slightly sticky.*—Adheres, but comes off easily.
  - *Sticky.*—Adheres and stretches somewhat.
  - *Very sticky.*—Adheres strongly and stretches decidedly.
- *Plasticity or cohesion.*—Measured by ability of material to form a wire between thumb and finger.
  - *Nonplastic.*—No wire formable.
  - *Slightly plastic.*—Wire formed but easily deformed.
  - *Plastic.*—Wire formed, requires moderate pressure to deform.
  - *Very plastic.*—Wire formed, requires much pressure to deform.

Consistence when moist.—Measured by resistance to rupture between thumb and finger.
- *Loose.*—Noncoherent.
- *Very friable.*—Crushes easily under very gentle pressure.
- *Friable.*—Crushes easily under gentle pressure.
- *Firm.*—Crushes under moderate pressure.
- *Very firm.*—Barely crushable.
- *Extremely firm.*—Cannot be crushed.

Consistence when dry.—Measured by resistance to rupture between thumb and fingers.
- *Loose.*—Noncoherent.
- *Soft.*—Breaks to powder or individual grains under very slight pressure.
- *Slightly hard.*—Weakly resistant; easily broken.
- *hard.*—Moderately resistant; barely breakable.
- *Very hard.*—Very resistant; not breakable.

SOIL CEMENTATION

Soils that are bound by calcium carbonate, silica, or oxides to a degree that typically does not soften under moisture, are said to be cemented. Grades of cementation are as follows:

- *Weakly cemented.*—Brittle and hard, but breakable in hands.
- *Strongly cemented.*—Brittle and very hard, but easily broken with hammer.
- *Indurated.*—Brittle, requires sharp blow to break with hammer.

SOIL REACTION (pH)

Soil reaction, or pH, values for this study were obtained with a small commercial colorimetric kit. General terms used to describe a range in pH are as follows:

Extremely acid	<4.5	Mildly alkaline	7.4–7.8
Very strongly acid	4.5–5.0	Moderately alkaline	7.9–8.4
Strongly acid	5.1–5.5	Strongly alkaline	8.5–9.1
Medium acid	5.6–6.0	Very strongly alkaline	≧9.1
Slightly acid	6.1–6.5		
Neutral	6.6–7.3		

USE OF SOILS AS STRATIGRAPHIC MARKERS

A soil is formed when the surficial layers of the earth undergo weathering at rates greater than those of erosion or deposition. Except where weathering proceeds very rapidly at the same time as erosion or deposition, a soil marks an interval of essential slope stability. In the La Sal Mountains, as elsewhere, not all soils are the product of modern climate, or even of the climate since the last major glacial stage of the Pleistocene. The major profile characteristics of most soils were developed during specific intervals of the Pleistocene, as will be demonstrated from their geologic position relative to deposits of known geologic age. Certain of these ancient soils, or paleosols (Hunt and Sokoloff, 1951), tend to retain some of their original profile characteristics, both where buried by younger deposits and where relict at the surface. Such soils, if identified with care and traced from one climatic environment to another, are reliable stratigraphic markers of the interval in which they formed.

Because soils are used as criteria for identifying the formations recognized in this study, it is desirable to summarize their previous use in other areas and discuss more fully how they are used in this report.

Weathered zones have long been recognized as stratigraphic markers of interglacial conditions in the pre-Wisconsin continental drift sheets of central United States, and they served as a basis for naming the Sangamon (Worthen, 1873) and Yarmouth (Leverett, 1898) interglacial stages. Since then, many workers have identified soils in both the pre-Wisconsin and Wisconsin drifts (Leighton, 1923, 1926; Kay and Apfel, 1929; Kay and Graham, 1943; and others). More recently, soils have been identified and extensively used as criteria for correlation in the Pleistocene loess sheets and alluvium of Nebraska and Kansas (Schultz and Stout, 1945, 1948; Schultz, Lueninghoener, and Frankforter, 1951; Thorp, Johnson, and Reed, 1951; Frye and Leonard, 1949, 1952; and others) and in the glacial and Pleistocene lake deposits of the Rocky Mountain region (Richmond, 1950; Hunt and Sokoloff, 1951; Richmond, Morrison, and Bissell, 1952; Hunt, 1954; and others).

BURIED SOILS AND SURFACE SOILS

Soils may either be buried by younger deposits or remain at the surface.

Burial implies that the soil is removed from the environment in which it formed. It may remain without significant megascopic change as a complete or, more commonly, a partly eroded buried soil; or it may undergo physical or chemical subsurface changes so extensive as to obscure or destroy its original characteristics. In the La Sal Mountains buried soils commonly have enough primary characteristics preserved to be clearly recognized.

Surface soils are continually subject to the effects of surface environment, including those of environmental change. They are thus "living" soils (Nikiforoff, 1955). However, profile characteristics formed under one environment may alter so slowly under others that they are essentially preserved and are readily distinguished from those of modern soils. In some, the megascopic aspects of nearly complete ancient zonal profiles may be so preserved. Such profiles have been aptly termed "relict" soils (Thorp, 1949), the surface remains of ancient soils. In the La Sal Mountains several surface soils are considered to be relict because they are clearly different from soils formed on deposits of the last major cycle of regional sedimentation in the same kind of local environment and because they are traceable without significant megascopic change to a buried position beneath younger deposits.

DETERMINATION OF GEOLOGIC AGE

The stratigraphic usefulness of a soil depends on the degree to which its identity and geologic age can be recognized. Either buried or relict soils can be dated as younger than the material on which they are developed. A buried soil is obviously older than superposed materials or unconformities. Either variety may display cumulative effects of environmental changes and may therefore be difficult to place precisely in the local history unless it can be traced to positions where unambiguous relations are seen.

For example, in figure 11*A* soil X, which has a relatively strongly developed profile, is formed on deposit X′ and is buried beneath deposit Y′, on which the relatively weakly developed soil Y is formed. Soil X can be traced from its buried position to a relict position on deposit X′, and in this position it retains the same dominant characteristics it had in a buried position. In other words, the effects of environment since soil X was buried have not altered the megascopic character of its profile beyond ready recognition. Such a soil can be used with confidence as a stratigraphic marker in both a buried and relict position.

In figure 11*B*, soil Y, which has a relatively weakly developed profile, is formed on deposit Y′ and is buried beneath deposit Z′, on which the relatively strongly developed soil Z is formed. Soil Y can be traced to a relict position on deposit Y′, but at the point of intersection with soil Z it changes in character to look like soil Z. In other words the effects of environment since soil Y was buried have altered the megascopic character of its profile beyond recognition. Such a soil, though a useful stratigraphic marker where buried, cannot be identified at the surface.

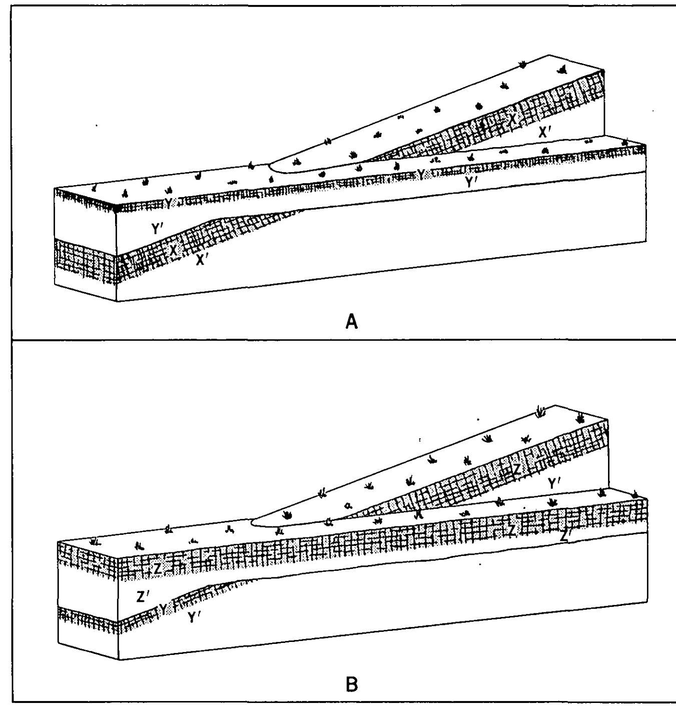


FIGURE 11.—Determination of the usefulness of relict soils as stratigraphic horizons.

A. Soil X which has a strongly developed profile, is formed on deposit X′ and is buried beneath deposit Y′ on which the weakly developed soil Y is formed. Where soil X is traceable to a relict position at the surface, it retains the same dominant characteristics it had in a buried position. Soil X is therefore a useful stratigraphic marker in both a relict and in a buried position.

B. Soil Y, which has a weakly developed profile, is formed on deposit Y′ beneath deposit Z′ on which the strongly developed soil Z is formed. Where soil Y is traceable to the surface, it changes in character to look like soil Z. In other words, soil Y is masked by soil Z at the surface, and can be recognized as a stratigraphic marker only where buried.

In some places a soil has been relict through many changes in environmental conditions. Such superposed profiles tend to resemble the most strongly developed of those soils that make up the composite, though commonly the effects of several episodes of soil formation can be distinguished in them. In general, these effects of lesser development cannot be referred on the basis of their appearance to a particular geologic age, though the profile as a whole is distinguishable as at least as old as its most strongly developed component.

SOIL PROFILES AS TIME-STRATIGRAPHIC UNITS

Where the interval during which the major profile characteristics of a soil can be narrowly bracketed in geologic time, that soil is a time-stratigraphic unit in the same sense used by the American Commission on Stratigraphic Nomenclature (1952, p. 1629). Because the interval in which the dominant characteristics of a soil were formed commonly represents only a part of a stage or substage, which are the lowest formal time-stratigraphic units, such an interval will simply be referred to informally as a soil-forming optimum.

DIFFERENCES IN SOILS ATTRIBUTABLE TO DIFFERENCES IN ENVIRONMENT

Factors influencing soil formation may be differentiated into those dependent on climate and the duration thereof and those dependent on the local drainage, slope, vegetation, organisms, and texture and mineralogic character of the parent material.

The broad changes in soil character that have been used as a basis for description and classification of great soil groups (Marbut, 1928, 1935; Baldwin, Kellogg, and Thorp, 1938; Thorp and Smith, 1949) are induced primarily by climate, and their geographic distribution corresponds closely with that of climatic provinces. In the Rocky Mountains, climatic provinces are telescoped in narrow altitude zones, to which the great soil groups correspond, as has been shown by Thorp (1931) in the Big Horn Mountains of Wyoming. Each of the soils recognized in the La Sal Mountains likewise changes its character from higher altitudes to lower. These changes, here called facies by analogy with the use of that term for lateral changes in rocks, range from a Brown Podzolic facies in the higher mountains through a Brown Forest facies and a Brown soil facies, respectively, to a Sierozem facies in the lower parts of the area.

The more local environmental factors also cause important soil variations. However, it is in many places possible to select areas where only one or two of these factors differ, thus giving a measure of control as to their relative influence. For purposes of comparing the characteristics of soils of different geologic age in the La Sal Mountains, well-drained profiles on gentle slopes at similar altitudes and on unconsolidated parent materials of similar textural and mineralogic character have been used. Composite or superposed soils displaying the effects of more than one soil-forming optimum have been avoided wherever possible.

DIFFERENCES IN DEGREE OF PROFILE DEVELOPMENT

"Degree of development" is a general expression for summarizing the differences in thickness of the profile, and in thickness, color, structure, consistence, pH, and accumulation of clay, sesquioxide, or calcium carbonate of individual horizons of soils formed on similar parent materials and under similar conditions of slope, drainage, and present-day vegetation.

In the La Sal Mountains, profiles of like facies of soils of different geologic age differ markedly in degree of development. For example, the B-horizon of the Brown soil facies of one soil is consistently thicker, redder, more blocky, more plastic, more clayey, and has a lower pH than the Brown soil facies of a second soil; but it is consistently less thick, less red, less blocky, less plastic, less clayey, and has a higher pH than that of a third soil. For purposes of comparison, it may be said that the profile of the first soil is better developed than the second and less developed than the third.

Furthermore, the profile of each soil maintains its relative degree of development, as compared with that of others, throughout each of its facies. In other words, a soil of given geologic age that is comparatively weakly developed in one facies is comparatively weakly developed in all.

In this report, the general terms "very weakly developed," "weakly developed," "moderately developed," "strongly developed," and "very strongly developed" are used to describe megascopically different degrees of relative profile development. These terms do not necessarily refer to the duration of soil formation or to pedologic maturity. Though the oldest soils are the most strongly developed, the sequence of soils in the La Sal Mountains does not progress from very strong to very weak.

Where other criteria are lacking, relative development can locally be used to identify a particular soil. However, it should be used with caution, and only after the geologic relations of each soil have been precisely determined and its profile characteristics have been carefully compared with those of other soils in the area.

Comparison of sequences of soils from different areas in terms of their relative development is believed to provide a valid basis for stratigraphic correlation, as will be subsequently discussed.

HARPOLE MESA FORMATION

DEFINITION

The oldest known Quaternary deposits of glacial association in the La Sal Mountains are till sheets and interfingering alluvial gravels that cap high interfluves around the flanks of the mountains and are distinctly older than the present canyons. The deposits have a very strongly developed soil formed on them, and they include two members separated either by a very strongly developed, persistent, buried soil or by an erosion surface. Within the canyons, but locally extending headward over these two older members, are interbedded or interfingering glacial, alluvial, colluvial, and eolian deposits representing a third member, on which a very strongly developed soil is also formed. These three depositional units are here defined as the lower, middle and upper members of the unit herein named the Harpole Mesa formation (fig. 9).

The three soils formed on the three members are so similar that no one is alone a criterion of a specific member. However, such soils were not found on deposits demonstrably younger than the Harpole Mesa formation, and they differ markedly from any soils known to be associated with such younger deposits. Therefore, where they are developed on deposits otherwise ascertained to be Pleistocene, they are considered to be a stratigraphic marker diagnostic of the Harpole Mesa formation. Where specifically identifiable, the soil at the top of the lower member of the formation is called the lower Spring Draw soil, that at the top of the Middle member is called the Middle Spring Draw soil, and that at the top of the upper member is called the Upper Spring Draw soil. Where forming a composite profile in which individual soils cannot be distinguished, they are called simply a Spring Draw soil.

TYPE LOCALITY

The Harpole Mesa formation is named from Harpole Mesa, on the northwest side of the North Mountain group. The type section is designated as that exposed on the south side of Spring Draw in SW1/4SW1/4 sec. 32, T. 25 S., R. 24 E. Here, the formation rests unconformably on the conglomerate of Pliocene(?) or very early Pleistocene(?) age (Hunt, 1958). The following section extends down the slope from the top of the mesa.

Type section of the Harpole Mesa formation

[Measured with hand level. Color symbols refer to Munsell Soil Color Charts, 1954]

Feet

Harpole Mesa formation:

Upper member: Upper Spring Draw soil on solifluction mantle (relict profile):

B horizon: Reddish-brown (2.5*YR* 5/4) unsorted nonbedded arkosic sandy loam with angular to subangular rock fragments, mostly of diorite and sandstone. Many fragments broken since deposition; some deeply disintegrated.
Structure: moderate medium columnar.
Consistence: slightly sticky, slightly plastic, friable, slightly hard.
Reaction: neutral.
Thickness, B horizon ---------------- 3

Abrupt irregular boundary.

Cca horizon: Pink (5*Y* 7/3) unsorted nonbedded arkosic sandy solifluction mantle containing angular to subangular rock fragments, mostly of diorite and sandstone. Many fragments broken; some deeply disintegrated.
Structure: structureless to weak thick platy.
Consistence: nonsticky, nonplastic, firm, slightly hard.
Reaction: strongly alkaline.
Thickness, Cca horizon -------------- 3

Total thickness, upper member ------- 6

Gradational contact.

Middle member: Middle Spring Draw soil:

B horizon: Light-reddish-brown (2.5*YR* 6/4) unsorted arkosic sandy till, containing subangular to subround fragments of diorite and sandstone.
Structure: moderate very coarse angular blocky.
Consistence: slightly sticky, slightly plastic, firm, hard; weakly cemented with clay and iron oxide.
Reaction: mildly alkaline.

Type section of the Harpole Mesa formation—Continued

Feet

Harpole Mesa formation—Continued

Middle member: Middle Spring Draw soil—Con.

B horizon—Continued
Interior of joint blocks leached of carbonate; secondary carbonate along structure planes probably associated with Cca horizon of upper Spring Draw soil above.
Thickness, B horizon ---------------- 4

Abrupt contact.

Cca horizon: Pink (7.5*YR* 7/4) unsorted arkosic sandy till, containing subangular to subround fragments of diorite and sandstone.
Structure: strong very coarse platy.
Consistence: nonsticky, nonplastic, firm, hard; strongly cemented with calcium carbonate.
Reaction: very strongly alkaline
Thickness, Cca horizon -------------- 15

Diffuse boundary.

Till: Light-yellowish-brown (10*YR* 6/4) unsorted nonbedded arkosic sandy silt, with subangular to round fragments of diorite and sandstone. Boulders as much as 6 feet in diameter. Compact, but friable. Some pods and veins of powdery calcium carbonate as much as 2 inches in diameter
Thickness, till --------------------- 28

Total thickness, middle member ------ 47

Abrupt disconformity.

Lower member: Lower Spring Draw soil:

B horizon: Light-reddish-brown (5*YR* 6/4) nonbedded well-sorted eolian fine sand and silt.
Structure: moderate, very coarse angular blocky.
Consistence: slightly sticky, slightly plastic, firm, hard.
Reaction: mildly alkaline except for concentrations of secondary carbonate along structure planes.
Thickness, B horizon ---------------- 6

Abrupt boundary.

Cca horizon: Light-brown (7.5*YR* 6/4) unsorted arkosic sandy till, containing abundant subangular to round fragments of diorite and sandstone.
Structure: moderate, very coarse platy.
Consistence: nonsticky, nonplastic, firm, hard.
Reaction: very strongly alkaline; moderately cemented with calcium carbonate.
Thickness, Cca horizon -------------- 7

Abrupt contact.

Cca horizon, continued: pink (7.5*YR* 7/4) well-sorted nonbedded eolian sand and silt.
Structure: very coarse platy.
Consistence: nonsticky, nonplastic, firm, hard.
Reaction: very strongly alkaline.
Thickness, Cca horizon, continued ---- 2

Type section of the Harpole Mesa formation—Continued

	Feet
Harpole Mesa formation—Continued	
Lower member: Lower Spring Draw soil—Continued	
Abrupt contact.	
Till: Light-brown (7.5*YR* 6/4) sandy; contains abundant subangular to round fragments of diorite and sandstone; mildly alkaline.	
Thickness, till	8
Abrupt contact.	
Alluvial sand and silt: Light-reddish-brown (5*YR* 6/4), crudely bedded; local bedded gravel lenses; mildly alkaline.	
Thickness, alluvial sand and silt	1.5
Abrupt contact.	
Till: Light-yellowish-brown (10*YR* 6/4) unsorted nonbedded arkosic sand and silt, containing subangular to round fragments of diorite and sandstone. Boulders as much as 5 feet in diameter. Structureless, compact and friable. Mildly alkaline throughout, but with a few thin lenticular layers of platy carbonate in upper few feet.	
Thickness, till	29
Abrupt contact.	
Eolian sand and silt: Light-reddish-brown (5*YR* 6/4), massive, nonbedded. Contains a few small stones. Mildly alkaline to neutral.	
Thickness, eolian sand and silt	2
Total thickness, lower member	55
Total thickness, Harpole Mesa formation	108
Angular unconformity.	
Conglomerate of Pliocene(?) or very early Pleistocene(?) age.	

This section is the only one found in which all three members of the Harpole Mesa formation are in superposition and separated by soils. Even here, the upper member is represented only by a relatively thin solifluction deposit. The upper member was also found on the south prong of Harpole Mesa where a saddle, cut into till of the middle member (fig. 12), contains distinctly morainal till and outwash gravel on which the upper Spring Draw soil is developed. This till extends down into the canyon of Placer Creek well below the base of the lower member (pl. 1 and fig. 13). Similarly, the outwash extends down Cane Hollow to the northwest.

Except on Harpole Mesa, the three members of the formation are not found in superposition, but they can be distinguished locally by their physiographic relations. For example, in many places referred to specifically below, gravels locally interfinger with till on each of three widespread erosion surfaces, each with a Spring Draw soil developed on it. From higher to lower, each surface was dissected before the next lower surface developed and was deposited upon. Three distinct cycles of Pleistocene deposition older than the upper Spring Draw soil can therefore be demonstrated. Correlation of these three generations with the three members of the Harpole Mesa formation is inferred from the fact that not more than three generations can be demonstrated anywhere in the area and that the stratigraphic succession of the deposits is alike. The difference in physiographic setting can be explained by the fact that Harpole Mesa probably was being lowered in a graben throughout deposition of the formation, owing to movements of underlying salt masses. Although the deposits at Harpole Mesa are not exposed along the graben faults, similar deposits in the Fisher Valley graben, north of the mapped area, are cut by faults.

LOWER MEMBER

The lower member of the Harpole Mesa formation comprises three facies: till, alluvial gravel, and eolian sand and silt. A Spring Draw soil is locally preserved on these deposits.

TILL

Till of this member crops out on Harpole Mesa, on the highest of three erosion surfaces along the southwest flank of the mountains near Pole Canyon, and high on Fisher Ridge along the northeast flank (pl. 1). It attains a lower limit of about 6,800 feet. Its surface is commonly smooth and lacks morainal expression. The till consists of compact, poorly sorted, arkosic sand containing numerous cobbles and boulders of fresh diorite or sandstone, many soled and faceted. However, some deeply disintegrated boulders occur throughout the deposits, well below any Spring Draw soil. The deposit north of Pole Canyon is 120 to 140 feet thick and appears to be derived from the ancestral canyon of Pack Creek because alluvial deposits of the same age upstream along Pole Creek contain no diorite. The deposit on Fisher Ridge contains fragments of vein-quartz and syenite porphyry that could only be derived from the head of Bachelor Basin.

ALLUVIAL GRAVEL

Alluvial gravel interfingers with till of the lower member at the type locality and locally on the highest of three erosion surfaces capped by alluvial deposits on which a Spring Draw soil is developed (pl. 1).

The deposits range from 25 to 150 feet in thickness and most are poorly sorted, crudely bedded accumulations of subround to round cobbles and boulders in an arkosic sandy matrix, with local lenses of well-bedded arkosic sand. Rock fragments are mostly of diorite

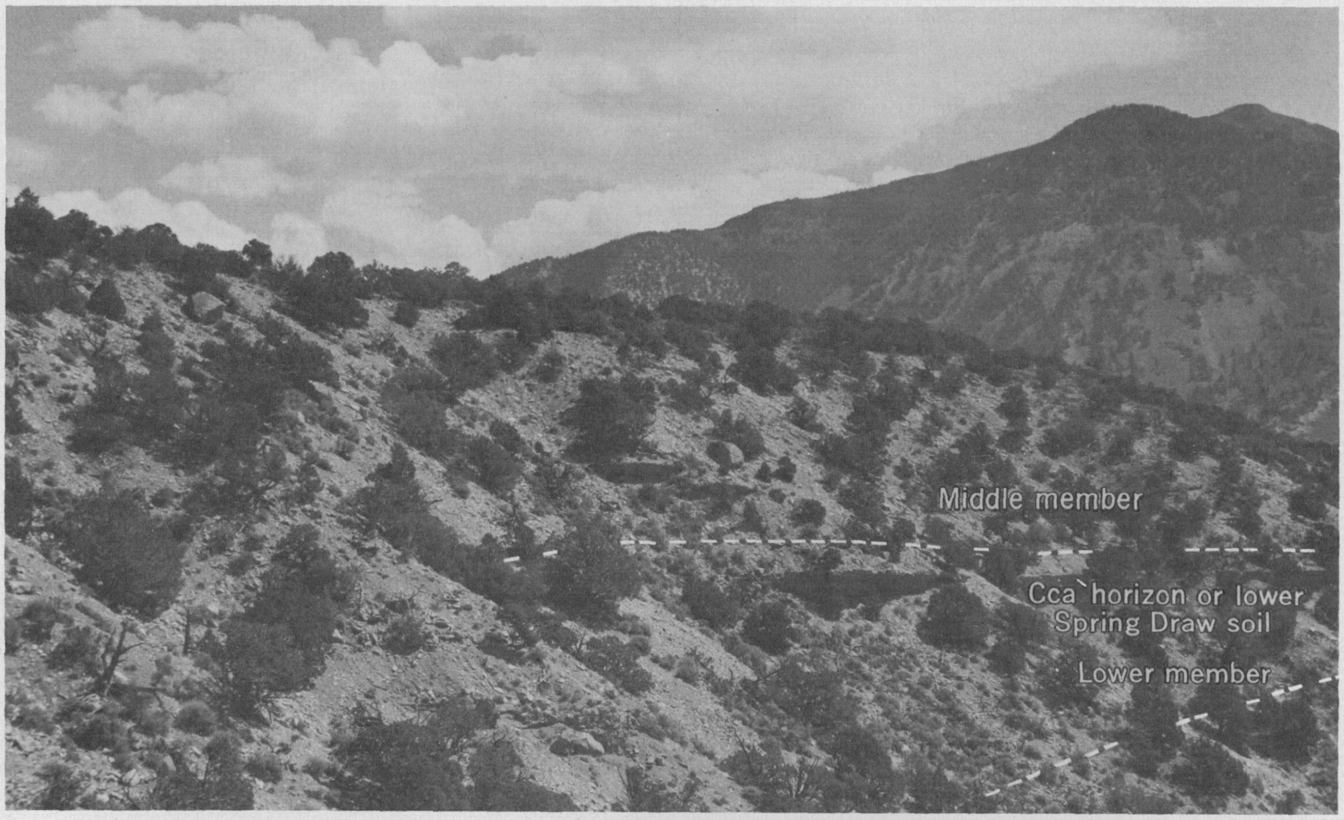


FIGURE 12.—Section of the lower and middle members of the Harpole Mesa formation in superposition on the south flank of Harpole Mesa.

or sandstone, though breccia, syenite porphyry, or monzonite are minor local components. Deposits along the Colorado River contain abundant granite, gneiss, schist, and basalt from outside the area. A few deeply disintegrated cobbles occur throughout most deposits.

The deposits have surface gradients ranging from as much as 400 feet per mile at the mountain front to 100 feet per mile along the Colorado River. Some, as on Dobe Mesa, Johnsons Up-On-Top, and Fisher Ridge, parallel the gentle dip slopes of the plateau rocks. Those on Johnsons Up-On-Top trend somewhat obliquely to Spanish Valley and diagonally across Mill Creek canyon (fig. 4). They represent the main drainage from the west slope of the mountains to the Colorado River. Deposits on the southwest and northeast flanks of the mountains represent alluvial fills on preexisting pediments. The fact that at canyon re-entrants the gravels interfinger with till shows that the fills coincided with glaciation. Gravels between canyon re-entrants are almost wholly sandstone derived from the local hogbacks. Along the Colorado River, gravels capping the highest of three terraces on which a Spring Draw soil is developed are correlated with the lower member of the Harpole Mesa formation because their projected gradient coincides at Moab with that of outwash of the lower member along the east side of Spanish Valley.

EOLIAN SAND AND SILT

Eolian sand and silt of the lower member of the Harpole Mesa formation is nowhere mappable, but about 25 feet of well-sorted light reddish-brown (5*YR* 6/4), fine sand and silt is interbedded with gravel of this member on the south flank of Harpole Mesa. Similar material, 6 to 8 feet thick, on which the lower Spring Draw soil is developed, caps both gravel and till of the lower member over most of Harpole Mesa. A layer about 2 feet thick lies at the base of the member at the type section. The material is compact, massive, and nonbedded. It has a coarse blocky jointing, and is composed almost wholly of quartz. The deposits would probably qualify as loess, though no mechanical analyses have been made.

EROSION SURFACE BETWEEN THE LOWER AND MIDDLE MEMBERS

Broad valleys, whose remnants range in depth from 150 to 250 feet in the mountains and decrease downstream to 60 to 75 feet along the Colorado River, dissect the lower member and antedate the middle

FIGURE 13.—Aerial view of the valley of Placer Creek on the north side of the North Mountain Group showing the type localities of the terminal moraines of the lower (*Qptl*) and upper (*Qptu*) members of the Placer Creek formation. A steeply sloping compound outwash fill, in which gravel of the upper member (*Qpau*) overlies gravel of the lower member (*Qpal*), extends from the lower moraine downstream along Placer Creek below the level of till (*Qhtu*) and outwash (*Qhau*) of the upper member of the Harpole Mesa formation. On Harpole Mesa, the type locality of the Harpole Mesa formation, till of the upper member of the formation (*Qhtu*) forms a moraine in a saddle which is cut in till of the middle member (*Qhtm*). This till in turn overlies till (*Qhtl*) and outwash gravel (*Qhal*) of the lower member of the formation. The type section of the Harpole Mesa formation lies on the north flank of the mesa above the road leading up Spring Draw. The plateau suface on the right of the photograph is underlain by till (*Qht*) of either the upper or lower members of the Harpole Mesa formation.

member of the Harpole Mesa formation. The mountain valleys, though modified by later glaciation, appear to have been steep sided, as much as half a mile wide, and with gradients as steep as 500 feet per mile.

The trough of Spanish Valley was shallower than it is now. The lower part of Castle Valley may have existed, but its present upper end was crossed by a stream that cut a shallow valley over 2 miles wide northwesterly across what is now Dobe Mesa. The canyon of the Colorado River had its present course and general form, but it was about 200 feet less deep than it is now.

The depth of erosion varies considerably. At Harpole Mesa, the middle member overlies the lower member in apparent conformity, whereas at Dobe Mesa the lower member was dissected approximately 350 feet before deposition of the middle member.

On the west side of the mountains, the lower valley of Pack Creek was dissected about 300 feet below the lower member, whereas in northern Spanish Valley cutting was less than 150 feet, and along the Colorado River, only 60 to 75 feet.

Remnants of an intermediate erosion surface on the southwest side of the mountains indicate that a broad steeply sloping pediment was cut at a depth between 200 and 300 feet below the surface of alluvial gravel of the lower member there.

On the east side of the mountains, the lower member on the high surface north and south of Beaver Creek was dissected 150 to 200 feet before the middle member was deposited.

MIDDLE MEMBER

The middle member of the Harpole Mesa formation comprises only two facies: till and alluvial gravel. A Spring Draw soil is locally preserved on these deposits.

TILL

Till of this member was recognized at the type locality, on the pediment south of Pack Creek known as Amasas Back, and between Chicken Creek and Spring Canyon on the southeast side of the mountains (pl. 1). The deposits are as much as 150 feet thick and consist of compact, nonbedded, unsorted mixtures of angular to subangular, locally soled and faceted boulders and cobbles in an arkosic sandy matrix. No striated fragments were observed. The material is largely composed of sandstone and diorite but includes a little shale. All grade downslope into outwash gravel.

The till attains a lower limit of about 6,600 feet. The surface of the till is mostly gently rolling. Hummocky morainal topography is locally preserved, however, and a distinct bouldery end moraine 20 to 50 feet high borders the till on Amasas Back (fig. 14). Except at the type locality, the till rests on an erosion surface that dissects the lower member and is cut by an erosion surface on which lie deposits of the upper member. All the deposits have a very strongly developed Spring Draw soil preserved on them.

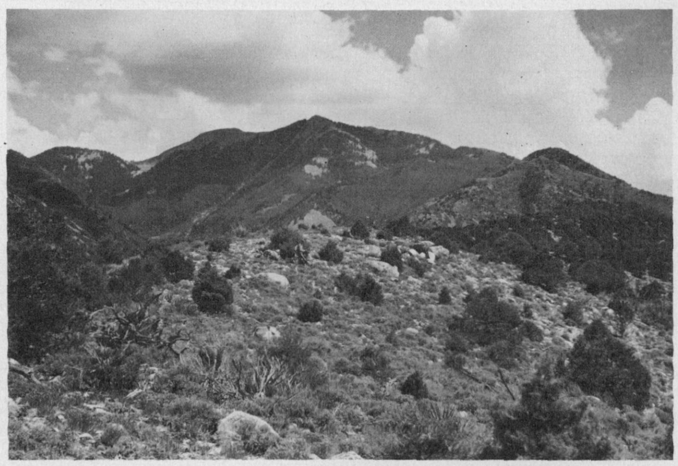


FIGURE 14.—Pre-canyon moraine of the middle member of the Harpole Mesa formation on Amasas Back divide, south of Pack Creek.

ALLUVIAL GRAVEL

Except at Harpole Mesa, where it lies between the lower and upper members, alluvial gravel of the middle member of the Harpole Mesa formation rests on an erosion surface that cuts the lower member and is itself truncated by an erosion surface on which lies the upper member. These conditions may be observed on Dobe Mesa north of Castle Valley, on Amasas Back south of Pack Creek, in the headwaters of Black Canyon on the southwest flank of the mountains, along Deep Creek and Beaver Creek on the east flank of the mountains, and along the Colorado River (pl. 1). The deposits grade into till at Harpole Mesa, on Amasas Back, and between Chicken Creek and Hang Dog Creek.

The alluvial gravel is commonly between 20 and 40 feet thick, but at Dobe Mesa and on the southwest flank of the mountains it is between 100 and 180 feet thick. It consists of subrounded to rounded cobble gravel in an arkosic, coarse sandy matrix. Boulders are relatively common, especially where outwash grades into till. The material is mostly diorite and sandstone, but it includes local syenite, syenite porphyry, monzonite, diorite or sandstone breccia, vein-quartz, or other rock types. Deposits along the Colorado River contain abundant granite, gneiss, schist, and basalt from outside the area.

Most deposits parallel present drainage, indicating that present stream courses were in general established, but the erosion surfaces on which they rest are broad-valley surfaces or pediments that clearly antedate the present canyons. The surface gradients of the deposits range from as much as 600 feet per mile at the mountain front to about 100 feet per mile along lower Spanish Valley and the Colorado River.

EROSION SURFACE BETWEEN THE MIDDLE AND UPPER MEMBERS

Erosion between deposition of the middle and upper members of the Harpole Mesa formation is represented by canyons and pediments similar to those cut between deposition of the lower and middle members.

At the north end of the mountains, Castle Creek probably captured the drainage across Dobe Mesa at this time. Part of the diversion was apparently due to subsidence of the Castle Creek graben, for gravel of the middle member on the north wall of the graben lies 400 feet above gravel of the middle member at Harpole Mesa on the graben floor. That stream erosion was also a factor, however, is indicated by the fact that the middle member at Harpole Mesa was dissected about 300 feet by Placer Creek and about

600 feet by Castle Creek before the upper member was deposited.

On the west side of the mountains, erosion by Pack Creek, following deposition of the middle member, was as much as 450 feet at the mountain front but decreased downstream to about 200 feet at the south end of Spanish Valley and about 120 feet at the north end of that valley. On the south side of the mountains, a broad pediment was cut 50 to 100 feet below the middle member near the mountain front and about 200 feet below those deposits at their present lowest extent. On the east side of the mountains, the canyons cut down between 150 and 200 feet along Deep Creek and Beaver Creek.

Little is known of conditions in the high mountain areas, except that no erosion appears to have taken place in Geyser Pass, where till of the upper member of the formation rests on the middle(?) Spring Draw soil, developed on till of the middle(?) member.

Along the Colorado River, erosion between the middle and upper members amounted to about 100 feet.

UPPER MEMBER

The upper member of the Harpole Mesa formation comprises six facies: till, alluvial gravel, alluvial-fan gravel, talus, frost rubble, and solifluction mantle. The upper Spring Draw soil is commonly preserved on the depositional surfaces of these deposits but was not observed on their dissected slopes.

TILL

Till of this member is widely distributed on broad valley surfaces and benches which project from the walls of canyons that dissect the middle and lower members. Examples are along Pack Creek Canyon, on Boren Mesa, on Brumley Ridge, on the north side of La Sal Creek, in the headwaters of Twomile Creek, and along Geyser Creek, Deep Creek, and Bear Creek. It attains its lower limit of 6,800 feet in Pack Creek Canyon.

The till differs from older tills in its more bouldery surface and in retaining its original morainal topography in many places, as along Pack Creek and on Harpole Mesa. Glacial scour associated with the till is preserved at Boren Mesa, whose western edge is rounded and smoothed in contrast to the ragged edges of unglaciated mesas.

The till averages from 10 to 20 feet in thickness but ranges from a veneer to more than 200 feet. It is generally composed of angular to subangular cobbles and boulders in a compact, unsorted, nonbedded matrix. Soled and faceted fragments are common, but striated fragments are rare. Where the till is derived from older outwash, it contains an appreciable amount of rounded material; where it rests on shale, the matrix contains much clay and shaly chips. The larger rock fragments, however, are mostly of diorite and sandstone. Deeply disintegrated fragments are scattered throughout the deposits.

ALLUVIAL GRAVEL

Alluvial gravel of the upper member of the Harpole Mesa formation is preserved on remnants of broad valley erosion surfaces along the walls of many canyons, on the lowest dissected pediment surface along the southwest flank of the mountains, and on remnants of a rock terrace 160 to 180 feet above the Colorado River. The gravel grades into till on Harpole Mesa, in the valley of Pack Creek, in the headwaters of Twomile Creek, and along Geyser Creek. In many other places it rests on remnants of the same erosion surface as, and only a short distance downstream from, till of the upper member. The disconformity at the base of the gravel commonly truncates the middle member of the formation, for example along Pack Creek (fig. 15), Beaver Creek, and Black Canyon. The very strongly developed upper Spring Draw soil on this gravel is overlapped in several places by the Placer Creek formation.

Most of the gravel surfaces are even and slope downstream at gradients ranging from 500 feet per mile at the mountain front to about 100 feet per mile in the lower valleys. Some are mantled by eolian material, but most are littered with fractured and exfoliated rock fragments. Desert varnish coats many of the fragments below an altitude of 7,500 feet.

The deposits are composed of subrounded to rounded gravel, cobbles, and boulders in an arkosic sandy matrix. Most of them are poorly sorted and crudely bedded. The rock fragments are mainly of diorite and sandstone, but on pediment surfaces between major canyons they are almost wholly sandstone, and those along the Colorado River contain much granite, gneiss, schist, and basalt. Deeply disintegrated material is common throughout. Deposits on broad valley surfaces range from a veneer to 50 feet in thickness; those on pediment surfaces commonly range from 20 to 80 feet in thickness, but near major canyon re-entrants are as much as 100 to 175 feet.

ALLUVIAL-FAN GRAVEL

Alluvial-fan gravel of this member occurs in several places in Castle Valley. Its original form is largely obscured by subsequent dissection, and most of it has been separated from its source. West of Porcupine Ranch (pl. 1) fan deposits composed wholly of locally derived angular sandstone gravel grade downslope into well-rounded alluvial gravel that contains much diorite. East of the confluence of Castle Creek and

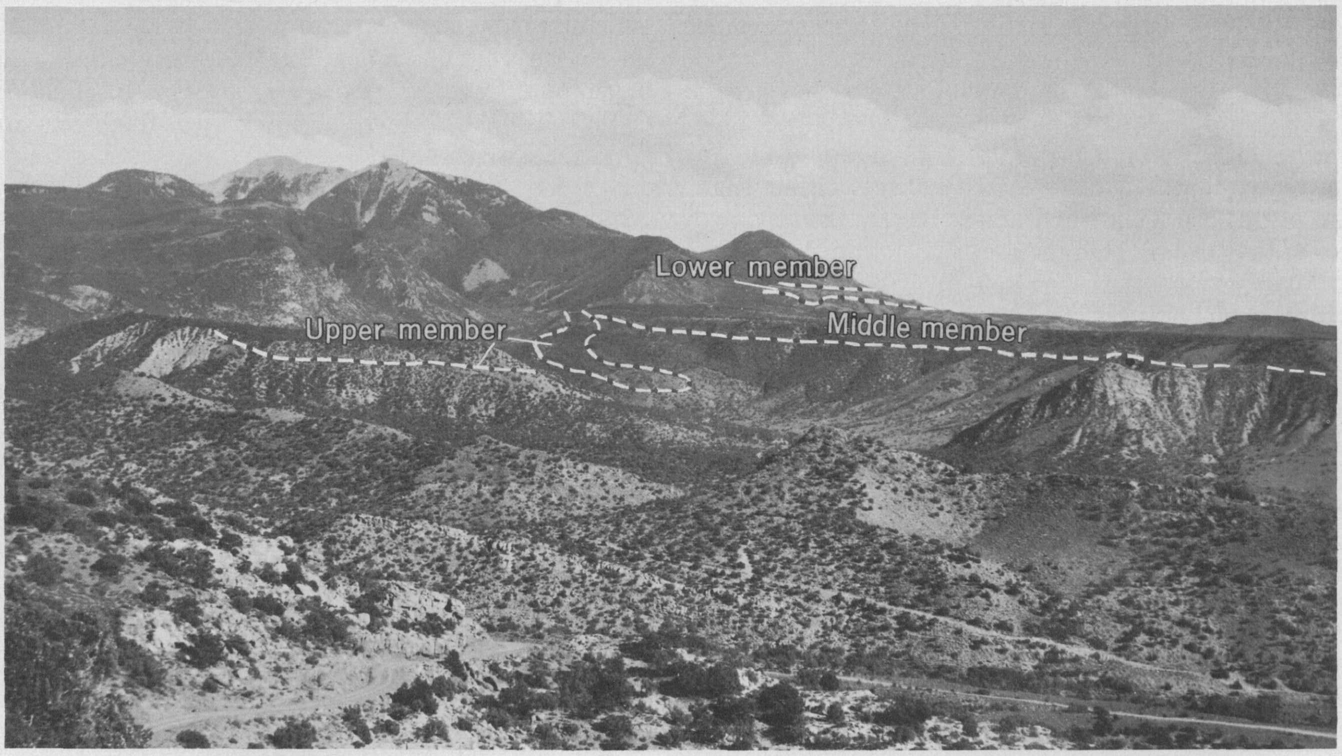


FIGURE 15.—Till of the upper member of the Harpole Mesa formation on the broad valley surface above the canyon of Pack Creek. Till and outwash of the middle and lower members of the formation cap successively higher pediment surfaces above the rim of the canyon to the south.

Spring Draw, other fan deposits composed of gravel of diorite and sandstone head against slopes cut 200 to 300 feet below alluvial gravel of the middle and lower members on Harpole Mesa. All the deposits are crudely bedded and poorly sorted.

TALUS

Talus of the upper member of the Harpole Mesa formation was found on a slope of about 20° at the foot of weathered and rounded sandstone cliffs east of the headwaters of Twomile Creek. The material consists of angular to subangular blocks of sandstone in a red sandy clay matrix. Some blocks are deeply disintegrated, and many have a crumbly rind that is 1 to 3 inches thick. The deposit has the upper Spring Draw soil developed on it and grades westward into diorite-bearing till of the upper member of the formation.

FROST RUBBLE

A frost-rubble facies of the upper member of the Harpole Mesa formation was found north of Geyser Creek along the base of the ridge east of Mt. Tomasaki and at the cattle guard on the road along the south wall of the valley of Placer Creek above Pinhook (pl. 1). (the term "frost rubble" is defined on p. 19.) The deposits consist of contiguous but loosely packed angular blocks of sandstone whose interstices are partly filled with compact sandy clay. Though they resemble talus, they lack cliff sources and appear to have formed in place. Partly stripped profiles of the upper Spring Draw soil are preserved on them. The deposit north of Geyser Creek lies on a slope of about 5° and grades downhill into till of the upper member. The deposit above Pinhook lies on a steep slope that dissects older till on the upland to the south. It is overlain by younger frost rubble of the Placer Creek formation.

SOLIFLUCTION MANTLE

Sheetlike solifluction deposits of silty sand and angular fragments of sandstone cover many slopes in upper Twomile Creek and Hang Dog Creek and grade laterally into till. Their surface is irregular. A crude bedding is present and an imbricate arrangement of slabs was noted locally. The deposits lie on bedrock and average about 6 feet thick.

FACIES OF THE HARPOLE MESA FORMATION, UNDIFFERENTIATED AS TO MEMBER

Many deposits, referable to the Harpole Mesa formation because of topographic position or stratigraphic relations, cannot be differentiated as to member, though some are demonstrably older than the upper member. Such deposits include till, alluvial gravel, talus, and eolian sand and silt. Only certain deposits of till which throw light on the extent of the glaciers are here discussed. These deposits cap Bald Mesa and Wilson Mesa west of the mountains (fig. 16). They lie above the upper member of the Harpole Mesa formation

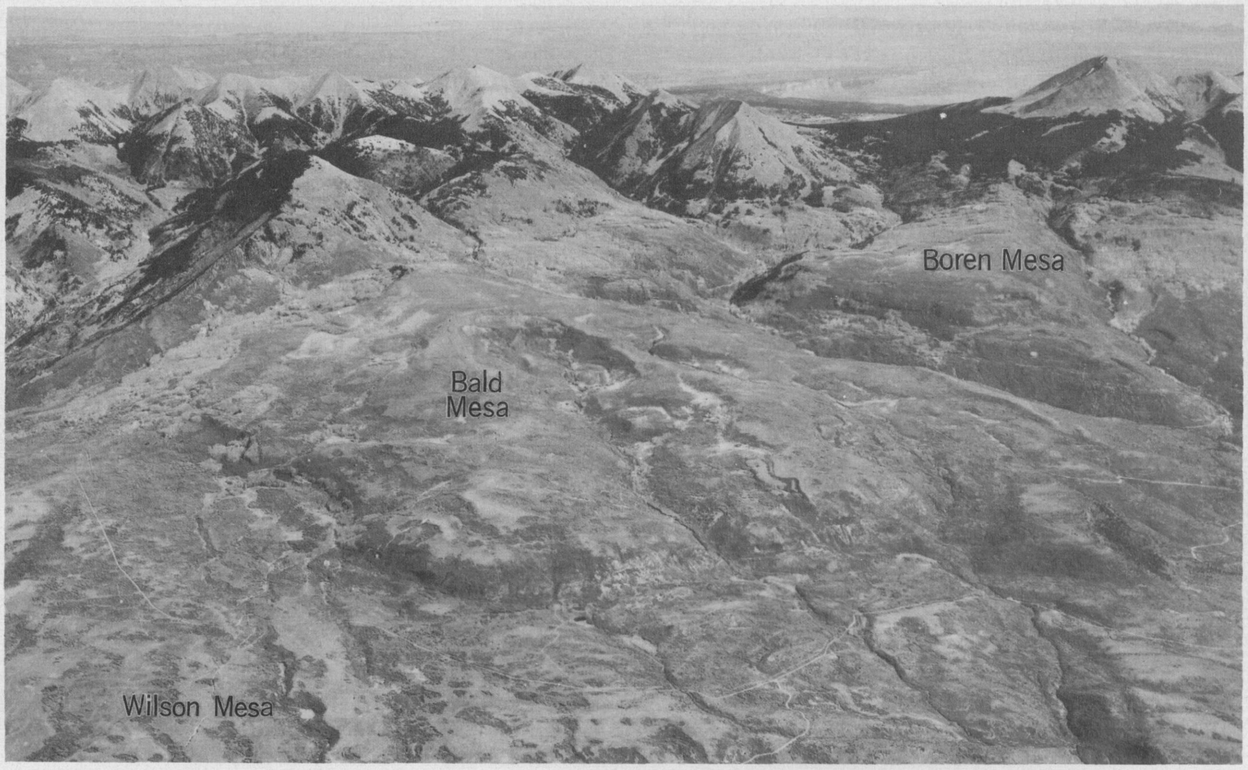


FIGURE 16.—Aerial view of the till-covered mesas west of the mountains. Boren Mesa is capped by till of the upper member of the Harpole Mesa formation. Bald Mesa and Wilson Mesa are capped by till of either the lower or middle members of the formation. The rounded appearance of the cliffs bordering the mesas is believed to be the product of glacial scour.

in the canyon of Mill Creek and could therefore belong to one of the older members or represent some still older glacial episode.

TILL ON BALD MESA AND WILSON MESA

Bald Mesa and Wilson Mesa are two successive steps in the plateau surface west of the mountains. Bald Mesa, the higher, is capped by till that rests on the Mancos shale and has a Spring Draw soil developed on it. The surface of the till retains no suggestion of morainal topography, though it is scalloped by landslides in the underlying shale. Boulders are rare on the surface except at breaks in slope. The till is 20 to 40 feet thick along the southeast rim of the mesa but thins to about 6 feet at the west rim. It is a compact sandy clay, derived largely from the underlying shale, and contains cobbles and boulders, some of which are of diorite breccia and sandstone breccia that could only have come from the Middle Mountain group to the southeast. The ice must therefore have moved northwest across Boren Mesa and across the sites of the present canyons of Horse Creek and Mill Creek before they were cut. Drag folds, overturned to the northwest, and closely spaced shear joints, dipping southeast, are exposed in the lower part of the till and in the underlying shale in a gully at the northern edge of the mesa, and are inferred to record the effects of overriding ice. Large angular blocks of shale are also displaced northwest from their bedrock source into the till.

The cliffs along the northwest rim of Bald Mesa are rounded at the crest as if by glacial scour and channeled in at least four places by broad U-shaped ravines (fig. 16), in contrast to the sharp and ragged aspect of most sandstone rimrock in the region. It is therefore inferred that the ice flowed over them onto Wilson Mesa.

The till on Wilson Mesa is a relatively thin veneer of boulders. For about half a mile west of Bald Mesa it consists of angular blocks of sandstone in a sandy matrix and appears to be wholly derived from the cliffs. Farther west, however, fragments of diorite become more and more abundant, and some vein-quartz, sandstone breccia, and diorite breccia are present. On the western part of Wilson Mesa the till grades into outwash gravel at an altitude of about 7,600 feet. This is approximately 9 miles from possible sources of ice in the Middle Mountain group, the maximum length of any glacier recorded in the La Sal Mountains.

Though most of this till on Wilson Mesa appears to be derived from the Middle Mountain group, smoky quartz found on the north part of the mesa suggests that some of the till was from the North Mountain group about 6 miles distant, where the only smoky quartz known in the mountains is exposed. (C. B. Hunt, oral communication, 1952).

VOLCANIC ASH IN HARPOLE MESA FORMATION

Reconnaissance in the badlands developed at the headwaters of Onion Creek in Fisher Valley, north of the mapped area, revealed a sequence of deposits containing layers of volcanic ash. The following section was measured at an altitude of 5,300 feet in bluffs on the south side of Onion Creek in the the NW¼NW¼ sec. 23, T. 24 S., R. 24 E. (Polar Mesa quadrangle).

Section in badland bluffs on south side of Onion Creek headwaters

	Thickness (feet) Unit	Total
Beaver Basin formation:		
Reddish loessial alluvium conformable contact	6–10	8
Placer Creek formation:		
Reddish loessial alluvium	5–15	20
Upper member:		
Sandy cobble gravel, calcareous coatings or weakly cemented in upper 3 to 4 feet	6–8	27
Disconformity.		
Lower member:		
Reddish loessial alluvium	5–15	38
sandy cobble gravel, calcareous coatings in upper 12–18 inches	8–15	50
Angular unconformity.		
Harpole Mesa formation:		
Reddish compact loessial aluvium	10	60
Middle member:		
Sand, strongly cemented with calcium carbonate	1–2	62
Volcanic ash, white, loose, fluffy	3	65
Red loessial colluvium and bedded alluvium with some interbedded silty gravel lenses	40	105
Clean sand with pebble to cobble gravel lenses	15	120
Red loessial colluvium and alluvium	20	140
Angular unconformity.		
Lower member:		
Hard, bedded alluvial sand with lenses of angular gravel containing cobbles of diorite. Several lenses of volcanic ash up to 6 inches thick in upper part	40	180

Correlation of these units with the Beaver Basin and Placer Creek formations is based on their similarity to the alluvial facies of these formations in Castle Valley and Spanish Valley, and on their character of weathering and carbonate accumulation in the upper part of each unit. Correlation of units with the Harpole Mesa formation is based on similarity of the weathering and carbonate accumulation in the upper part of this unit to the Sierozem facies of the Spring Draw soil.

Downstream to the northwest of the described section another unit of reddish compact colluvium and alluvium containing interbedded gravel, but no volcanic ash, lies disconformably beneath the units correlated with the Placer Creek formation and in angular unconformity on the unit correlated with the middle member of the Harpole Mesa formation. It has a soil like the Spring Draw soils formed on it and is believed to represent the upper member of the Harpole Mesa formation.

A sample of the ash was collected from the unit correlated with the middle member of the Harpole Mesa formation and examined by Ray E. Wilcox, who reported as follows (written communication, December 30, 1951).

The material is relatively unaltered volcanic ash, of which the major portion is clear colorless glass, occurring as fragments (up to 1 mm diam.) of thin, slightly curved walls of vesicules. Many of the fragments have rib-like projections, some curved, some straight, marking the junctures with other walls. (Apparently vesiculation prior to fragmentation had proceeded so far that most vesicules had approached polygonal shapes and were separated by thin walls of only moderate curvature and no great thickening at the junctures.) Elongate fragments are present in moderate numbers, and these contain closely packed tubular vesicules parallel to length of the fragments. Occasionally ovaloid vesicules are found in these and other fragments. Refractive index of the glass is very uniform, lying between 1.499 and 1.501.

With the glass are found moderate amounts of quartz and alkali feldspar fragments, both included in the glass and as separate loose fragments. Scattered tiny particles of carbonate (calcite?) account for the strong but brief effervescence of the sample when treated with HCl. The occasional black flakes seen under the binocular were not encountered in immersion mounts. They may be biotite.

Irregular and streak-like portions, up to several mm in size, are cemented by light orange material which is soft and does not effervesce more strongly than the loose ash in 6N HCl, nor does it show any immediate effects of the acid treatment. In immersion mounts, this material is seen to consist of aggregates of grains, less than 0.005 mm in size, showing moderate birefringence and low positive relief (vs. 1.540). Individual particles adhere to the smooth surfaces of the glass fragments but do not appear to be replacing the glass nor to be an alteration of the glass. The material may be a member of the montmorillonite series.

This glass has refractive index identical to that of the Pearlette ash. Although the grain size is much larger, the shape-habit of the fragments is similar to that of the Pearlette. The common occurrence of curved junctures and tubular vesicules of some fragments have been taken by Swineford and Frye as critical features of the Pleistocene ashes of Kansas and Nebraska, separating them from the Pliocene ashes in which such features are uncommon.

Subsequently the sample was further examined by H. A. Powers, who noted the chevkinite which he has found also to be common to the Pearlette volcanic ash bed and to other volcanic ash beds in Western United States. Mr. Powers supplied the analytical data given in table 6, which further suggests a correlation of the ash bed from the middle member of the Harpole Mesa formation in the La Sal Mountains with the Pearlette volcanic ash of Kansas. Concerning this he

TABLE 6.—*Comparison of analyses of cleaned glass shards (all phenocrysts and detrital material removed) from the ash bed in the middle member of the Harpole Mesa formation, the Pearlette volcanic ash bed at its type locality, and other Pleistocene ash beds*

	1	2	3	4	5	6	7	8
STANDARD ROCK ANALYSIS [Analysts: 1-6, 8, D. F. Powers; 7, P. Monalto; all F determinations, P. Monalto]								
SiO_2	72.63	72.58	73.10	72.82	72.78	73.58	*69.82	70.90
Al_2O_3	11.71	11.86	11.72	11.71	11.80	11.79	12.49	11.99
TiO_2	.12	.12	.13	.14	.12	*.07	.12	*.19
Fe_2O_3	.56	.64	.58	.59	.57	*.31	*.77	*1.07
FeO	.90	.88	.90	.95	.93	*.38	1.10	*1.50
MnO	.04	.04	.04	.04	.04	.04	.05	.05
MgO	.17	.15	.08	.12	.11	.17	.13	.22
CaO	.67	.59	.56	.62	.51	.74	.59	.94
Na_2O	3.00	2.99	2.73	2.73	3.31	3.37	*2.32	*3.92
K_2O	5.44	5.37	5.64	5.59	4.93	4.52	*6.72	*3.81
P_2O_5	.02	.01	.01	.02	.02	.02	.06	.01
H_2O+	3.80	3.94	3.64	3.76	4.07	4.22	4.96	4.54
H_2O-	.19	.25	.25	.23	.20	.24	.23	.25
F	.15	.14	.15	.13	.13	*.06	*.10	*.06
QUANTITATIVE SPECTROGRAPHIC ANALYSIS [Analyst: P. R. Barnett]								
B	<0.001	<0.001	0.001	0.001	0.001	*0.01	*0.006	0.001
Ba	.02	.02	.03	.03	.02	*.006	*.005	*.08
Be	.001	.001	.001	.001	.001	.001	.001	.001
Cu	.0004	.0006	.0006	.0004	.0004	.0002	.0008	.0005
Ga	.0026	.0026	.0026	.0028	.0026	*.0015	*.0033	*.0023
La	.01	.01	.01	.02	.01	*<.004	.01	.01
Mo	.0006	.0006	.0006	.0006	.0005	.0006	.0006	.0005
Nb	.006	.006	.006	.007	.006	*.003	.007	*.002
Pb	.004	.004	.003	.004	.004	.003	*.002	*.001
Sc	<.0002	<.0002	<.0002	<.0002	<.0002	*.0005	<.0002	*.0007
Sn	.001	.001	.001	.001	.001	*.0004	.001	.001
Sr	<.001	.001	.001	.001	.001	.001	.001	.001
Y	.01	.01	.01	.01	.009	*.003	.01	.01
Yb	.0009	.0009	.0009	.001	.0009	*.0003	.0008	.0009
Zr	.03	.03	.03	.03	.02	*.01	.04	*.05

* Difference believed significant.
1. Ash bed in middle member of Harpole Mesa formation; heavy minerals present as phenocrysts: ferroaugite, chevkinite, magnetite, ilmenite, fayalite, pink zircon, colorless zircon. Field no. 50-61A, lab no. E1886.
2. Pearlette ash, type locality, under Borchers fauna above Cudahy fauna. Field no. 57-P-12, lab. no. D1758.
3. Sappa ash, Nuckolls County, Nebr. Field no. Buck OS-35. lab. no. E1827.
4. Pearlette ash, Roberts County, Tex. Field no. DT-3-56, lab. no. D1763.
5. Ash in Saltaire core, 548-ft depth. Core no. 179, lab. no. D1764.
6. Ash in Saltaire core, 646-ft depth. Core no. 212, lab. no. E1820.
7. Hagerman ash, near Hagerman, Idaho. Field no. 55-P-183, lab. no. E1810.
8. Blanco ash, at type locality Blancan fauna, Blanco, Tex. Field no. 58-P-201, lab. no. E2219.

reported as follows (written communication, August 16, 1959):

The ash from Onion Creek, the ash from a depth of 546 feet in the lakebeds at Saltaire, Utah, and samples from several outcrops of the Pearlette ash of the Great Plains, are similar in physical character, contain similar phenocryst minerals, and are similar in chemical composition. These samples differ in several characteristics from a number of other ash deposits of Late Cenozoic age that have been studied. In my opinion, these data justify correlation of the ash bed in Onion Creek with the Pearlette ash of the Great Plains.

SPRING DRAW SOILS

DEFINITION AND TYPE LOCALITY

The Spring Draw soils are very strongly developed weathering profiles which were observed on deposits of the Harpole Mesa and older formations but not on younger deposits. Soils of this kind occur at the top of each of the three members of the Harpole Mesa formation, where these members are superposed (p. 25). Where distinguishable, they are specifically referred to as the lower, middle, and upper Spring Draw soils (fig. 9). Their type locality is that of the Harpole Mesa formation. The three members are only locally superposed, however, so that any single soil is in general known only to be younger than the particular member involved.

RELATIONS TO THE PLACER CREEK FORMATION

The relations of the Spring Draw soils to the Placer Creek formation are readily established. At Harpole Mesa, the upper Spring Draw soil is dissected by Placer Creek, exposing outwash that grades upstream into a moraine of the lower member of the Placer Creek formation (fig. 12). The Spring Draw soils are therefore all older than the Placer Creek formation.

Beyond the limits of Harpole Mesa, the uppermost Spring Draw soil is consistently either overlain by the Placer Creek formation or by a disconformity older than that formation (fig. 17). The Spring Draw soils are differentiated from those in and on the Placer Creek formation because of their greater degree of development.

FACIES OF THE SPRING DRAW SOILS

The Spring Draw soils occur in four different facies; that is, their profiles change with altitude through four different great soil groups.

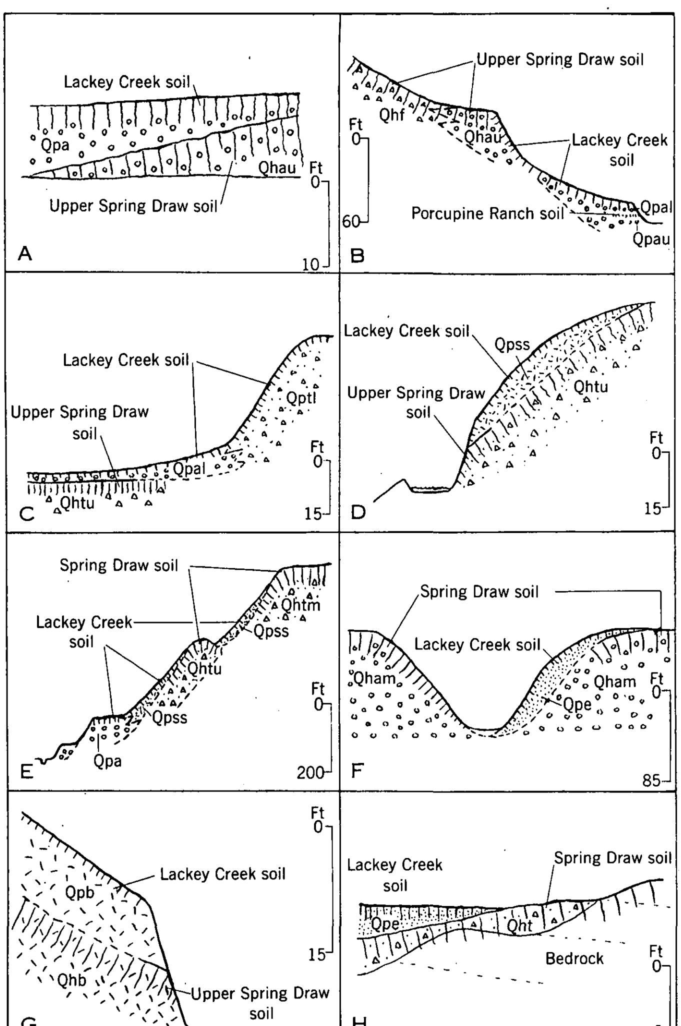
The four facies are, in order of descending altitude, a Brown Podzolic facies, a Brown Forest facies, a Brown soil facies, and a Sierozem facies.

Typical profiles of each major facies showing their general character diagrammatically are sketched in figure 18.

BROWN PODZOLIC FACIES

Brown Podzolic facies[1] of the Spring Draw soils are developed on the Harpole Mesa formation above a lower limit that ranges in altitude from 8,600 to 9,200 feet (pl. 2 and fig. 19). Upward, they extend to 10,500 feet, the highest altitude at which deposits of the Harpole Mesa formation were found. Present vegetation on the facies is a spruce-fir climax and an aspen and meadow subclimax.

[1] The term "Brown Podzolic" is applied to this facies with some misgiving because the profile is considerably thicker, redder, and more clayey than profiles usually so referred. Possibly it should be called a Red Podzolic soil because it has many aspects of that group. However, since like geologically younger Brown Podzolic soils, it is at higher altitudes than Brown Forest soils and since it appears to differ from them mainly in color and degree of development, it is arbitrarily grouped as a Brown Podzolic soil.



A. A sketch of the wall of a draw tributary to Cane Hollow, in Castle Valley southeast of Round Mountain. The Upper Spring Draw soil, developed on alluvial gravel of the upper member of the Harpole Mesa formation (*Qhau*), is overlain conformably by alluvial gravel of the Placer Creek formation (*Qpa*), on which a younger soil, the Lackey Creek soil, is formed.

B. A sketch of relations of alluvial fans on the south side of Castle Valley, west of Porcupine Ranch. The Upper Spring Draw soil, developed on alluvial fan gravel (*Qhf*) and outwash gravel (*Qhau*) of the upper member of the Harpole Mesa formation, is dissected by an erosion surface that is overlain by outwash deposits of the lower (*Qpal*) and upper (*Qpau*) members of the Placer Creek formation, on which the Lackey Creek soil is formed.

C. A sketch along an irrigation ditch on the upland at the head of Twomile Creek, east of Mount Peale. The Upper Spring Draw soil, developed on till of the upper member of the Harpole Mesa formation (*Qhtu*), is overlain by thin deposits of bouldery outwash (*Qpal*) from a nearby moraine (*Qptl*) of the lower member of the Placer Creek formation on which the Lackey Creek soil is formed.

D. A sketch along the same ditch as in *C*, a quarter of a mile to the east on the south side of the valley of Twomile Creek. The Upper Spring Draw soil, developed on till of the upper member of the Harpole Mesa formation (*Qhtu*), is here overlain by solifluction mantle of the Placer Creek formation (*Qpss*) on which the Lackey Creek soil is formed.

E. A sketch of the south wall of the valley of Pack Creek, about one mile upstream from the Pack Creek Ranch. Spring Draw soils are developed on till of the middle member of the Harpole Mesa formation (*Qhtm*) on the rim of the valley, on the valley wall that dissects this till, and on a moraine of the upper member of the formation (*Qhtu*) which lies on the valley wall. This moraine is, in turn, cut by a slope which is overlain by slope-wash mantle (*Qpss*) and alluvial gravel (*Qpa*) of the Placer Creek formation, on which the Lackey Creek soil is formed. Younger terraced deposits and soils lie in the bottom of the valley.

F. A sketch of a ravine that dissects the high surface south of Pack Creek, about half a mile south of locality *E*, above. A Spring Draw soil is developed on outwash gravel of the middle member of the Harpole Mesa formation (*Qham*) and on the north slope of the ravine. On the south side of the ravine, this soil is overlapped by eolian sand and silt of the Placer Creek formation (*Qpe*) on which the Lackey Creek soil is formed.

G. A sketch of the north slope of Wilson Mesa above Pinhook at the cattle guard along the county road. The Upper Spring Draw soil is developed on a frost rubble deposit of the upper member of the Harpole Mesa formation (*Qhb*) and is overlain by a frost rubble deposit of the Placer Creek formation (*Qpb*) on which the Lackey Creek soil is formed.

H. A sketch along the county road up Brumley Ridge at the Summerville Ranch. Here, a Spring Draw soil, developed across a thin deposit of till of the Harpole Mesa formation (*Qht*) and into the underlying bedrock is overlain by eolian sand and silt of the Placer Creek formation (*Qpe*) on which the Lackey Creek soil is formed.

FIGURE 17.—Some geologic relations of the Spring Draw soils.

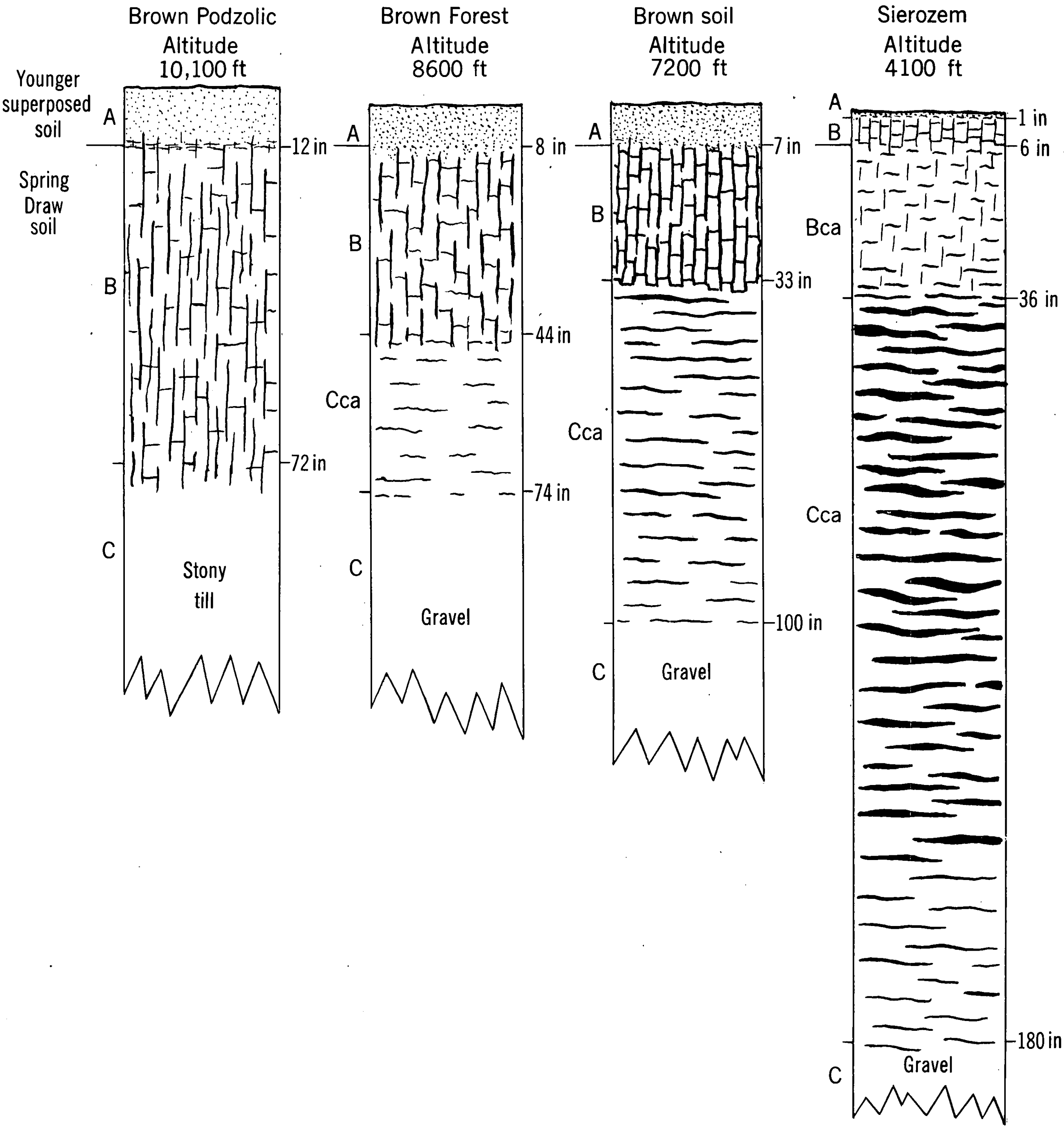


FIGURE 18.—Typical profiles of the four major facies of the Spring Draw soils, showing diagrammatically their general character and thickness.

The Brown Podzolic facies were observed on till, alluvial gravel, and coarse colluvial deposits of different lithologic composition. Typical relict and buried profiles on till composed mostly of diorite, a mixture of diorite and sandstone, wholly of sandstone, and of gray clay derived from the Mancos shale are given in sections 1 to 5.[2]

[2] Sections referred to throughout the text are given under "Stratigraphic Sections of Soils."

Profiles of the Brown Podzolic facies are fairly uniform regardless of texture or lithologic characteristics of the parental material.

An A horizon, associated with relict profiles, appears to be superposed on a truncated B horizon and is therefore considered to be of post-Spring Draw origin.

The B horizon ranges in maximum thickness from about 4½ feet at an altitude of 9,200 feet to as much as 8 feet at 10,500 feet (table 7). It is commonly reddish

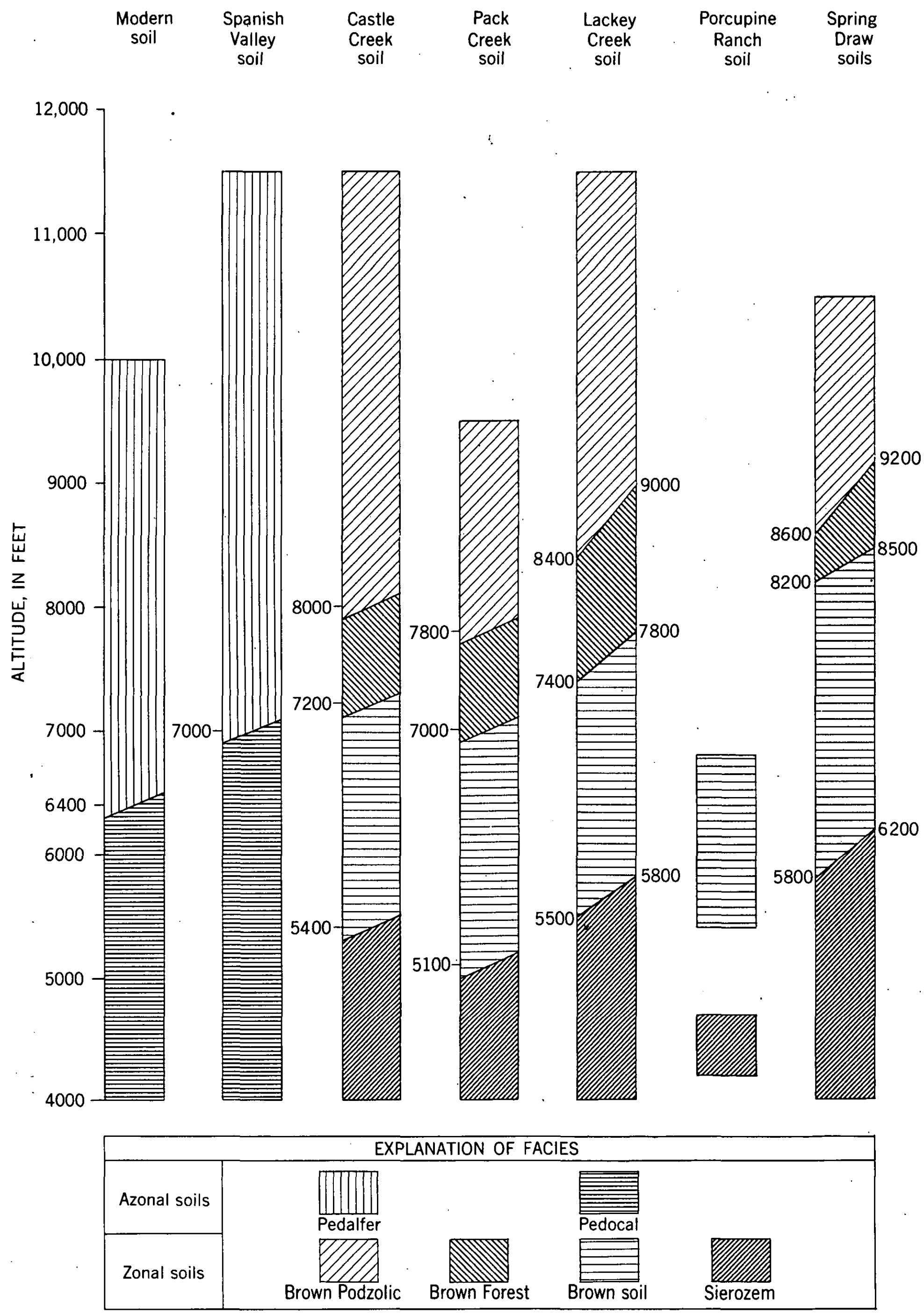


FIGURE 19.—Range in altitude of facies and facies changes of soils of different geologic age in the La Sal Mountains, Utah. Altitudes beside columns are average altitudes of facies changes.

brown (5*YR* 6/4) to yellowish red (5*YR* 4/6). On Mancos shale, the hue is less red (7.5*YR*) and the chroma is more red (6). The structure of the B horizon is in general moderate to strong, coarse to medium, angular blocky. Some buried profiles on till display a crude platy parting, perhaps a relict till structure rather than a soil structure. The material is commonly plastic, considerably more so than the parental rock, and reflects obvious clay accumulation. The reaction (pH) ranges roughly from medium acid in the lower part of the altitude range at about 9,200 feet to strongly acid at about 9,600 feet, very strongly acid to 10,000 feet, and extremely acid above 10,000 feet. Kaolinized feldspar grains and deeply rotted fragments are more common in the B horizon than below.

BROWN FOREST FACIES

Brown Forest facies of the Spring Draw soils are developed on the Harpole Mesa formation in an altitude

TABLE 7.—*Comparison of profile characteristics of Brown Podzolic facies of soils of different geologic age*

Soil	B horizon								
	Altitude range (feet)	Thickness	Color		Structure			Plasticity	Reaction (pH)
			Hue	Chroma	Grade	Class	Type		
Spanish Valley	Above 7,000	4–6 inches	7.5–10*YR*, mostly 10*YR*	2–4	Structureless			Nonplastic	6.0–7.0
Castle Creek	Above 8,000	10–22 inches	7.5–10*YR*, mostly 10*YR*	2–4, mostly 4	Weak	Fine to medium	Crumb to subangular blocky	Nonplastic	5.0–6.5
Pack Creek	Above 7,800	4–8 inches	10*YR*	2–4,	Weak	Fine to medium	Subangular to angular blocky	Nonplastic	6.0–6.5
Lackey Creek	Above 8,400 to 9,000	3.0–4.5 feet	5–10*YR*, mostly 7.5*YR*	2–6, mostly 6	Weak to moderate	Fine to medium	Angular to subangular	Mostly slightly plastic	4.5–6.5
Porcupine Ranch	Not observed								
Spring Draw	Above 8,600 to 9,200	4.5–8.0 feet	10*R*–7.5*YR*, mostly 5*YR*	2–6, mostly 6	Moderate to strong	Coarse to medium	Angular blocky	Plastic	4.0–5.5

range whose upper limits are roughly between 8,600 and 9,200 feet, and whose lower limits are roughly between 8,200 and 8,500 feet (pl. 2, fig. 19).

Brown Forest facies were observed on till and alluvial gravel of all three members of the Harpole Mesa formation. (See sections 6 and 7 and fig. 20.)

An A horizon was observed on the Brown Forest facies only in relict profiles, where it rests on a truncated B or Cca horizon and is therefore believed to be the product of a younger soil-forming environment.

The B horizon ranges in maximum thickness from about 4 feet at 8,200 feet, the lower altitude limit of the facies, to about 5 feet at 9,200 feet, the upper limit (table 8). It is reddish brown (2.5*YR* 5/4) to red (2.5*YR* 5/6) though locally on mantle composed mainly of sandstone the hue is 10*R* and the chroma is less (2–3). The structure is commonly moderate, medium to coarse, angular to subangular blocky. The material is slightly plastic to plastic and is more clayey than the parent mantle. The reaction (pH) ranges from slightly acid (6.2) at lower altitude to medium acid (5.5) at higher. Kaolinized feldspar and rotted rock fragments are more common in the B horizon than in the underlying parent mantle.

The Cca horizon ranges in maximum thickness from about 4 feet at an altitude of 8,200 feet to about 3 feet at 9,200 feet, the highest altitude at which carbonate was observed in the profile. The carbonate tends to form thin coatings on the under sides of rock fragments and along openings but does not cement the matrix. The color ranges from reddish brown (2.5*YR* 5/4) to light brown (7.5*YR* 6/4), locally mottled reddish yellow (7.5*YR* 6/6). The horizon is commonly structureless, but where developed across fine-grained parent mantle, such as eolian sand and silt, it has a moderate coarse blocky to weak coarse platy structure. The plasticity is commonly similar to or only slightly more than that of the parent mantle. The reaction (pH) of the horizon ranges from neutral (7.0) at higher altitudes to moderately alkaline (8.0) at lower altitudes. Krotovinas (animal burrows), filled with material from the B horizon, are locally present.

BROWN SOIL FACIES

Brown soil facies [3] of the Spring Draw soils occur in an altitude range whose upper limits are roughly between 8,200 and 8,500 feet and whose lower limits are roughly between 6,200 and 5,800 feet (pl. 2, fig. 19).

[3] The term "Brown soil" is applied to this facies with some hesitancy because the profile is thicker, redder, and more clayey than most soils referred to the Brown soil group. Near Monticello, Utah, this profile has been classed as a Chestnut soil by the U.S. Department of Agriculture. However, since it occupies the same relative environment as younger Brown soils, between a Brown Forest facies above and a Sierozem facies below, it will be grouped arbitrarily as a Brown soil.

FIGURE 20.—Brown Forest facies of a Spring Draw soil developed on till of the Harpole Mesa formation along a gully on the north side of Bald Mesa. The profile extends through the till and into the underlying Mancos shale.

TABLE 8.—*Comparison of profile characteristics of Brown Forest facies of soils of different geologic age*

Soil	Altitude range (feet)	B horizon								Cca horizon						
		Thickness	Color		Structure			Plasticity	Reaction (pH)	Thickness	Color		Structure			Reaction (pH)
			Hue	Chroma	Grade	Class	Type				Hue	Chroma	Grade	Class	Type	
Spanish Valley [1]	7,000–6,500	No B horizon								2–6 inches	10*YR*	3–4	Structureless			about 7.0
Castle Creek	7,800–7,000	4–10 inches	7.5*YR*	3–4	Weak	Fine	Granular to blocky	Nonplastic	6.5–7.3	12–24 inches	7.5–10*YR*	3–4	Structureless			7.0–7.5
Pack Creek	8,000–7,200	2–4 inches	10*YR*	3–4	Structureless			Nonplastic	6.1–6.5	6–12 inches	10*YR*	3–4	Structureless			7.0–7.5
Lackey Creek	9,000–7,400	2.5–3 feet	2.5–7.5*YR*	3–6, mostly 4.5	Weak to moderate	Fine to medium	Subangular to angular blocky	Mostly slightly plastic	6.1–7.0	1.5–3 feet	7.5–10*YR*	3–6	Structureless to— Weak	Fine to medium	Platy	7.0–8.0
Porcupine Ranch	Not observed															
Spring Draw	9,200–8,200	4–5 feet	10*R*–2.5*YR*	2–6 mostly 6	Moderate	Medium to coarse	Subangular to angular blocky	Mostly plastic	5.5–6.2	3–4 feet	2.5–7.5*YR*	3–6	Weak to moderate	Medium to coarse	Blocky to platy	7.0–8.0

[1] Spanish Valley soil has an azonal alkaline A–C profile, whose characteristics in an arbitrary altitude range are given here under Cca horizon.

The lower boundry of the facies is somewhat uncertain, because Spring Draw soils are known from only a few localities below 6,500 feet.

The Brown soil facies is more extensively preserved than any other facies of the Spring Draw soils. It is developed on till and alluvial gravel of all three members of the Harpole Mesa formation and on talus and alluvial-fan deposits of the upper member. Some of these deposits are composed of a mixture of diorite and sandstone; others are mainly of sandstone. The facies is also formed on eolian deposits that are predominantly of quartz sand and silt. Megascopically, all profiles on these several kinds of parent materials appear alike. A relict profile on till composed of diorite and sandstone is given in section 8 and is illustrated in figure 21. Buried profiles on similar material are described on page 26. The profile is also preserved on bedrock, especially on the west side of the mountains. Though not studied here, its horizon of carbonate accumulation is prominent on rock in many places.

An A horizon was observed only in association with relict profiles of the Brown soil facies, in most of which it rests on a truncated B horizon and is not of the Spring Draw origin. In a few places, however, an abrupt disconformity occurs within the A horizon, separating a younger dark-gray-brown, friable, nonplastic material with a granular structure above from a dark-gray, hard, plastic material with a strong fine columnar structure below. The lower material grades diffusely down into the underlying B horizon and is considered of Spring Draw origin.

In general, the B horizon ranges in maximum thickness from about 40 inches at 5,800 feet near the lower altitude limit of the facies, to about 50 inches at 8,500 feet at the upper altitude limit (table 9). However, at the type locality of the Harpole Mesa formation, the B horizon of the lower Spring Draw soil is as much as 6 feet thick. The profile is commonly thinnest on clay and thickest on gravel. In many places it is partly or wholly truncated by erosion. The color is fairly consistently reddish brown (2.5*YR* 5/4), but on mantle composed primarily of sandstone or red shale it tends to be weak red (10*R* 4/4). The chroma, though commonly 4, may be as much as 6. The structure is strong to moderate, medium to coarse columnar to angular

FIGURE 21.—Brown soil facies of a Spring Draw soil developed on sandy till of the Harpole Mesa formation along an eroded irrigation ditch leading west across the central part of Wilson Mesa.

TABLE 9.—*Comparison of profile characteristics of Brown soil facies of soils of different geologic age*

Soil	Altitude range (feet)	B horizon								Cca horizon						
		Thickness (inches)	Color		Structure			Plasticity	pH	Thickness (inches)	Color		Structure			pH
			Hue	Chroma	Grade	Class	Type				Hue	Chroma	Grade	Class	Type	
Spanish Valley	[1] 6,500 5,500	No B horizon								2–6	5–10*YR*	3–4	Structureless			About 7.5
Castle Creek	7,200–5,400	6–12	7.5–10*YR*, mostly 10*YR*	3–4	Weak	Fine	Columnar to blocky	Nonplastic	7.0–7.8	24–36	7.5–10*YR*	3–4	Structureless or— Weak to strong	Fine	Blocky to columnar	8.0–8.5
Pack Creek	7,000–5,100	4–8	5–10*YR*	3–4	Structureless or— Weak	Fine	Columnar to blocky	Nonplastic to slightly plastic	7.0–7.5	12–24	5–10*YR*	3–4	Structureless			7.5–8.5
Lackey Creek	7,800–5,500	24–36	5–10*YR*, mostly 5*YR*	4	Weak to moderate	Fine to coarse	Columnar to blocky, mostly blocky	Nonplastic to slightly plastic	6.8–7.5	36–60	5–10*YR*	2–4	Structureless or— Weak to moderate	Strong	Platy	8.0–9.0
Porcupine Ranch	[2] 6,800 5,400	6–24	5–7.5*YR*	3–4	Weak	Fine to medium	Angular to subangular blocky	Nonplastic to plastic	6.5–7.2	12–30	7.5*YR*	4	Structureless			7.5–8.0
Spring Draw (Soils)	8,500–5,800	40–50	2.5–10*YR*	4–6, mostly 4	Moderate to strong	Medium to coarse	Columnar to angular blocky	Plastic to very plastic	6.0–7.0	48–72	5–7.5*YR*	1–4	Coarse	Massive or medium to strong	Blocky to platy	8.0–9.0

[1] Spanish Valley soil has an azonal alkaline A-C profile, whose characteristics in an arbitrary altitude range are given here under Cca horizon.
[2] Range in which soil is preserved; probably not equivalent to original extent.

blocky. The material is commonly plastic to very plastic and displays noticeable clay accumulation as compared with the underlying parent mantle. The reaction (pH) ranges roughly from slightly acid (about 6.0) at the upper altitude limit of the facies to neutral (about 7.0) at the lower altitude limit. The contact between the B horizon and Cca horizon is in most places a sharp, irregular solution surface.

The Cca horizon ranges in maximum thickness from about 4 feet at an altitude of 8,200 feet to about 6 feet at 8,000 feet (table 9). Carbonate is generally more abundant than in the Cca horizon of the Brown Forest facies, though no quantitative measurements have been made; it is concentrated along openings and thickly coats the rock fragments. The matrix is commonly cemented to a degree that the horizon forms a ledge at exposures. The horizon is white (5*YR* 8/1) to pink (7.5*YR* 7/4) and is either massive and structureless or has a coarse, medium to strong, platy to blocky structure. It is commonly more plastic than the underlying mantle. Leached samples, however, display no marked clay accumulation except where the lower part of the B horizon overlaps the upper part of the horizon of carbonate enrichment to form a Bca horizon. The reaction (pH) ranges from moderately alkaline (about 8.0) at higher altitudes to strongly alkaline (about 9.0) at lower altitudes. Krotovinas, filled with material from the B horizon, commonly extend into, and in places through, the Cca horizon.

The base of the Cca horizon is generally very indistinct, and carbonate concentrations extend to considerable depths as streaks and lenses. Where the parental Quaternary deposits are thin, calcium carbonate tends to be concentrated on top of the bedrock or along bedding and joint planes in it; much of it may have been brought in laterally rather than from above. For descriptive purposes, the base of the Cca horizon is arbitrarily placed at the top of the highest deposits not significantly impregnated with carbonate, even though streaks may be found well below.

SIEROZEM FACIES

Sierozem facies of the Spring Draw soils are developed on deposits of the Harpole Mesa formation in an altitude range whose upper limits are roughly between 6,200 and 5,800 feet (pl. 2, fig. 19). Its lower limits are unknown, but the lowest exposures observed are at about 4,100 feet on terrace gravel of the upper member of the Harpole Mesa formation 160 feet above the Colorado River and 2 miles downstream from Moab.

A Sierozem facies is developed on alluvial gravel of each of the three members of the Harpole Mesa formation and on talus which cannot be identified as to member. It is confined to deposits along the Colorado

River and on the plateau northeast of Spanish Valley, where its parental material is a mixture of diorite and sandstone. A typical profile is given in section 9.

Relict profiles of the Sierozem facies appear to be partly composite. The A horizon is thin and friable and contains so little organic matter that it is probably modern. In places, part or all of the Bca horizon also appears to be of post-Spring Draw origin. This is illustrated in section 9 where material high in the Bca horizon is redder, much more friable, much less clayey, much less compact, and much less plastic than that in the lower part, which is pink, hard, clayey, compact, and plastic. Furthermore, the mottled calcareous accumulations in the upper part of the Bca horizon are clearly younger than the broken thick caliche fragments relict from the Spring Draw soil and may be the product of later leaching and frost action acting on a once-thicker horizon of carbonate accumulation of that soil. Composite origin is further suggested by the physical relations of the two parts of the Bca horizon. In some places, as shown in section 9, the upper part rests in abrupt contact on the lower part; in others it rests abruptly on the Cca horizon; in still others it is lacking, and material like that in the lower part of that section overlies the Cca horizon beneath a very thin friable A horizon.

The lower part of the Bca horizon has a maximum thickness of about 40 inches (table 10). It is believed to be of Spring Draw origin because it is sticky, plastic, firm, and hard, as are the B horizons of other Spring Draw facies, and because it occurs in buried profiles beneath the Placer Creek formation. Material like that of the upper part of the Bca horizon shown in section 9 was not found in buried profiles.

The Cca horizon ranges in maximum thickness from about 10 feet at an altitude of 6,000 feet to 16 to 18 feet at an altitude of 4,100 feet (table 10). Where less thick, truncation of the profile by erosion can be demonstrated. In some places, erosion has left only broken thick caliche fragments to suggest its former presence. Where more fully preserved, the profile is characterized by an intense accumulation of calcium carbonate which fills most interstices in the deposit, thoroughly impregnates the matrix, and thickly coats the rock fragments. In general, it also weakly to strongly cements the deposit. The horizon is white (5*YR* 8/1) to pink (7.5*YR* 7/4) and is either massive and structureless or has a strong coarse platy structure. Accumulated calcareous matter causes the material to be plastic, but leached samples are no more plastic than the underlying parent mantle. The reaction (pH) of the horizon is consistently strongly to very strongly alkaline (about 9.0).

TABLE 10.—*Comparison of profile characteristics of Sierozem facies of soils of different geologic age*

Soil	Altitude range (feet)	B or Bca horizon								Cca horizon							
		Thickness	Color		Structure			Plasticity	Reaction (pH)	Thickness	Color		Structure			Reaction (pH)	Cementation
			Hue	Chroma	Grade	Class	Type				Hue	Chroma	Grade	Class	Type		
Spanish Valley	below 5,500 [1]	No B or Bca horizon								2–6 inches	5–7.5*YR*	3–4	Structureless			7.5–8.0	None.
Castle Creek	below 5,400	About 6 inches	5–10*YR*	4	Structureless or weak platy			Nonplastic	8.0–8.5	36–48 inches	5–7.5*YR*	3–4	Structureless			8.5–9.0	None.
Pack Creek	below 5,100	No B or Bca horizon								About 24 inches	5–10*YR*	3–4	Structureless			8.0–8.5	None.
Lackey Creek	below 5,500 to 5,800	6–24 inches	2.5–7.5*YR*	4	Structureless or— Moderate	Medium	Blocky	Slightly plastic	9.0	65–85 inches	2.5–7.5*YR*	2–4	Structureless or— Medium to fine	Strong	Platy	8.8–9.0	Weak.
Porcupine Ranch	[2] 4,700–4,200	6± inches	2.5*YR*	6	Structureless			Nonplastic	8.0–8.5	24–36 inches	2.5*YR*	4	Structureless or— Weak	Coarse	Columnar	8.0–8.5	None.
Spring Draw	below 5,800 to 6,200	24–36 inches	5*YR*	3	Structureless			Plastic	9.0	10–18 feet	2.5–7.5*YR*	1–4	Structureless or— Strong	Coarse	Platy	9.0	Weak to strong.

[1] Spanish Valley soil has an azonal alkaline A-C profile, whose characteristics in an arbitrary altitude range are given here under Cca-horizon.
[2] Range in which soil is preserved, probably not equivalent to original extent.

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SUMMARY OF GENERAL CHARACTERISTICS OF SPRING DRAW SOILS

The Spring Draw soils display certain characteristics which set them apart from all others in the area.

1. The average upper altitude limit of each of the four facies is higher than for like facies of any other soils (fig. 19).
2. The B or Bca horizon ranges in maximum thickness from 24 inches at an altitude of 4,100 feet, its lowest observed altitude, to 120 inches at 10,500 feet, its upper limit. At any given altitude its average thickness is consistently greater than the B horizon of any younger soil (fig. 56).
3. The hue of the B horizon ranges from 10*R* to 7.5*YR*, with most profiles displaying a hue of 2.5*YR* or 5*YR*. This is consistently redder than the B horizon of any other soil (fig. 57*A*).
4. The chroma of the B horizon ranges from 3 to 6 and is generally 4 to 5, thus tending to be somewhat higher than that of any other soil (fig. 57*B*). Color values are in general like those of other soils (fig. 57*C*).
5. The structure of the B horizon ranges from prismatic to subangular blocky. It is, however, more commonly columnar or angular blocky than that of the B horizon of any other soil, regardless of the texture of the parent mantle (fig. 58*A*). The structure is also more commonly coarse or medium (fig. 58*B*) and more commonly strongly developed (fig. 58*C*) than that of the B horizon of any other soil.
6. The material of the B horizon is commonly more plastic than that of the B horizon of any other soil (fig. 59) and thus probably contains more illuviated clay than the B horizons of younger soils.
7. The reaction (pH) of the B horizon ranges from about 7.0 at an altitude of 5,800 feet to about 4.0 above 10,000 feet (fig. 60). Throughout this altitude range, the pH tends to be lower at any given altitude than that of the B horizon of any younger soil.
8. The Cca horizon ranges in maximum thickness from about 3 feet at an altitude of 9,200 feet, its upper limit, to as much as 17 feet at 4,800 feet (fig. 61). At any given altitude it is consistently thicker than the Cca horizon of any younger soil.
9. The reaction (pH) of the Cca horizon ranges from about 7.0 at an altitude of 9,200 feet, its upper limit, to about 9.0 at altitudes below 6,000 feet. At any given altitude above about 5,500 feet the pH tends to be higher than that of any younger soil (fig. 60). Below 5,500 feet, the pH is greater than that of any younger soil except the Lackey Creek soil which at such altitudes is also about 9.0.
10. Although no quantitative measurements have been made, the thickness, impregnation, and cementation of the Cca horizon of Spring Draw soils suggest that at any given altitude it contains more accumulated calcium carbonate than the Cca horizon of any other soil.
11. The Spring Draw soils are developed on slopes that are mostly lower than 20°, and no profile differences attributable to slope erosion during soil formation were noted. The slopes are believed to have been essentially stable at the time and mostly well drained. Since formation, the soils have been extensively eroded, commonly more so on steep slopes than on gentle slopes.

EROSION SURFACE BETWEEN THE HARPOLE MESA FORMATION AND THE PLACER CREEK FORMATION

Erosion younger than the Harpole Mesa formation and older than the Placer Creek formation is recorded by canyons somewhat shallower than those cut just prior to deposition of the upper member of the Harpole Mesa formation.

On the west side of the mountains, the downcutting generally amounted to 200 to 250 feet, though Mill Creek, an exception, appears to have cut about 500 feet, well below Horse Creek at their junction. At the north end of Spanish Valley, erosion amounted to about 150 feet and along the Colorado River to about 90 feet.

On the south side of the mountains, the upper member of the Harpole Mesa formation was dissected only 20 to 50 feet along the upper sectors of the major streams but as much as 200 feet along the lower sectors.

On the east side of the mountains, erosion was between 80 and 150 feet in most places, but locally it was as much as 200 feet.

At the north end of the mountains, the upper member of the Harpole Mesa formation was dissected at least 140 feet at the east end of Castle Valley, but near Round Mountain it is overlapped conformably by alluvial gravel of the Placer Creek formation. This suggests that the west end of the Castle Valley graben continued to collapse during this interval.

Most of the erosion is believed to have postdated development of the upper Spring Draw soil, for that soil was not observed on eroded slopes of the upper member of the Harpole Mesa formation.

PLACER CREEK FORMATION

DEFINITION

The unit here named the Placer Creek formation includes interfingering or intergradational deposits that overlie the Harpole Mesa formation or an erosion surface truncating it. In places the formation likewise disconformably overlies deposits older than the Harpole Mesa formation. The formation typically has the Lackey Creek soil developed on it (fig. 9), and is the youngest formation that bears this soil. It is commonly either cut by shallow valleys containing the Beaver Basin or Gold Basin formations, or it is overlain by those younger formations.

The Placer Creek formation includes two members. Where these are superposed, a weakly developed zonal soil, the Porcupine Ranch soil, is locally preserved on the lower member. This soil, however, is commonly cut out by a disconformity that separates the two members. The upper member generally has the distinct and strongly developed Lackey Creek soil developed on it. This soil is also commonly developed on deposits of the lower member that are not buried by the upper.

The Placer Creek formation comprises nine facies: till, alluvial gravel, alluvial sand and silt, alluvial-fan gravel, talus, solifluction mantle, frost rubble, slope-wash mantle, and eolian sand and silt (fig. 9). Five of these can be distinguished in both lower and upper members. Four can be related only to the formation as a whole. Within each member, the facies interfinger or intergrade laterally or vertically so as to indicate virtual continuity of deposition. Sketches of these relations at a few specific localities are shown in figure 22.

Genetically similar facies of the lower and upper members are alike in all respects except stratigraphic position. Each facies will therefore be described as a unit before discussing the subdivision into members.

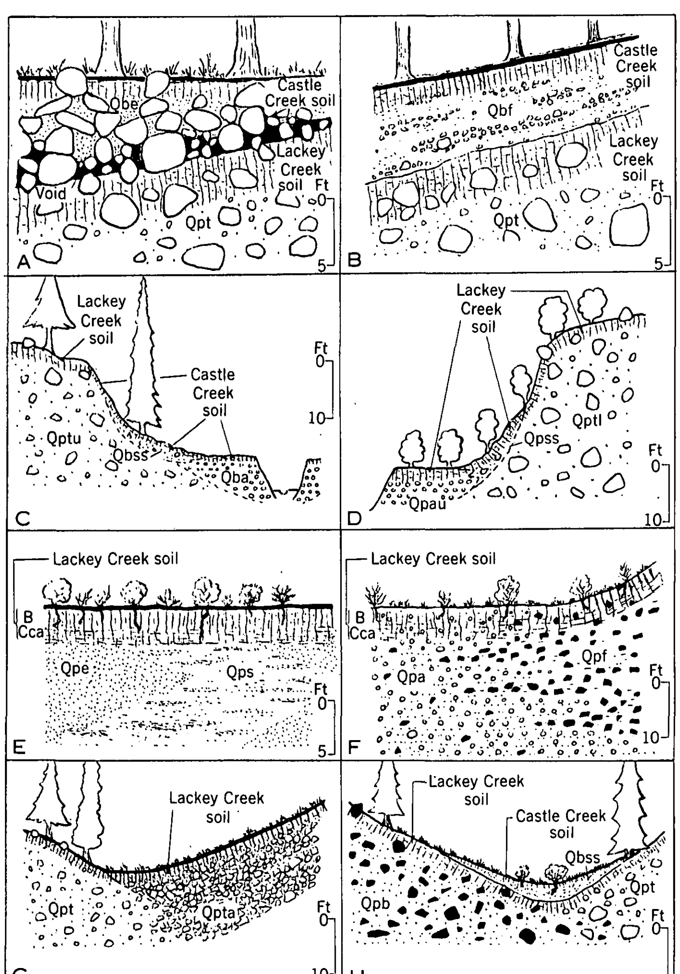
As all facies of the formation are nowhere represented in a single section, the type locality for the formation is defined stratigraphically with respect to its till, to which all other facies are then correlated on the basis of their interfingering or intergradational relations.

TYPE LOCALITY

The Placer Creek formation is named from the canyon of Placer Creek on the west side of the North Mountain group, where a high terminal moraine of the lower member occupies the area between Pinhook and the point where the road to Miners Basin crosses Placer Creek (NW¼ sec. 16, T. 26 S., R. 24 E.) (pl. 1). The toe of the moraine, altitude 8,100 feet, is about 2 miles upstream from the lower limits of till of the upper member of the Harpole Mesa formation on Harpole Mesa (fig. 13) and lies in a canyon that dissects the upper Spring Draw soil developed on that till and associated outwash.

In Miners Basin, 2 miles up the canyon from the terminal moraine of the lower member of the formation, is a similar but smaller terminal moraine of the upper member. Small outwash deposits extend discontinuously downstream from this moraine through a trench eroded in the moraine of the lower member.

Evidence for distinguishing the two moraines as separate members of the formation was found in several places in Castle Valley, downstream from the lower moraine where outwash deposits from the two moraines form a compound fill. Outwash from the lower moraine has a weakly developed zonal soil, the Porcupine



A. Sketch of till (*Qpt*) of the Placer Creek formation, on which Lackey Creek soil is developed, overlain by eolian sand and silt (*Qbe*) of Beaver Basin formation which fills the interstices between boulders at the surface of the till and has the Castle Creek soil formed on it. Location—at sharp bend in road to Miners Basin at an altitude of about 9,000 feet.

B. Sketch of till (*Qpt*) of the Placer Creek formation, on which Lackey Creek soil is developed, overlain by alluvial fan gravel (*Qbf*) of Beaver Basin formation, on which Castle Creek soil is developed. Location—in wall of arroyo in cirque east of Pilot Mountain.

C. Sketch of till (*Qptu*) of the upper member of the Placer Creek formation, on which the Lackey Creek soil is developed, overlain by outwash gravel (*Qba*) and slope wash (*Qbss*) of the Beaver Basin formation, on which the Castle Creek soil is developed. Location—along Dark Canyon Creek near Dark Canyon Lake.

D. Sketch of till (*Qptl*) of the lower member of the Placer Creek formation eroded by a shallow valley that contains outwash (*Qpau*) and solifluction debris (*Qpss*) of the upper member of the formation. The Lackey Creek soil is formed across the surface of all three deposits. Location—along Brumley Creek at an altitude of 8,400 feet.

E. Sketch of alluvial sand and silt of the Placer Creek formation (*Qps*) grading laterally into eolian sand and silt of the formation (*Qpe*). The Lackey Creek soil is developed across both deposits. Location—in the wall of a draw on the south side of South Mountain.

F. Sketch of outwash gravel (*Qpa*) of the Placer Creek formation, composed mostly of diorite, interfingering with alluvial fan gravel (*Qpf*) composed wholly of sandstone. Lackey Creek soil is developed across the surface of both deposits. Location—in the wall of an arroyo between Lackey Creek and Trough Springs Creek west of La Sal.

G. Sketch of till of the Placer Creek formation (*Qpt*) grading laterally into talus of that formation (*Qpta*). The Lackey Creek soil is developed across the surface of both deposits. Location—along a draw tributary to Dry Fork from the north at an altitude of about 10,600 feet.

H. Sketch of till (*Qpt*) of the Placer Creek formation, composed largely of diorite, grading laterally into solifluction debris (*Qpb*) of the formation composed largely of sandstone. The Lackey Creek soil is formed across the surface of both deposits, and is overlain by slope wash mantle (*Qpss*) of the Beaver Basin formation on which the Castle Creek soil is developed. Location—in the wall of an arroyo tributary to Deep Creek from the north at an altitude of about 10,800 feet.

FIGURE 22.—Some stratigraphic relations of deposits of the Placer Creek formation.

Ranch soil, formed on it, and this soil is in turn cut by a disconformity buried by outwash from the upper moraine. On this, the relatively strongly developed Lackey Creek soil is formed. The fact that the Porcupine Ranch soil is here in a Brown soil facies, similar to but more weakly developed than the Lackey Creek soil, clearly indicates that an interval of nondeposition and weathering under an ameliorated climate separated deposition of the two members.

The upper moraine of the Placer Creek formation in Miners Basin lies downstream from moraines of the Beaver Basin formation on which a moderately developed soil, the Castle Creek soil, is formed. Both moraines of the Placer Creek formation and the Lackey Creek soil are overlapped by alluvial fans, talus, frost rubble, or eolian sand and silt of the Beaver Basin formation. The two moraines of the Placer Creek formation therefore older than deposits of the Beaver Basin formation and separated from them by the Lackey Creek soil.

FACIES OF THE PLACER CREEK FORMATION

TILL

Till of the Placer Creek formation forms two distinct end moraines, whose stratigraphic and physiographic relations are similar to those at the type locality, in the lower part of 29 canyons in the mountains (pl. 1). The average altitude of the moraines of the lower member is 9,230 feet, that of the moraines of the upper member is 9,670 feet. More than two moraines are present in a few places, as along Horse Creek and Beaver Creek; and locally, as on Grand View only one moraine was found. Lateral moraines are extensively preserved, and ground moraine mantles the canyon floors as far upstream as the end moraines of the Beaver Basin formation.

The end moraines are large, and they are as much as 150 feet in height. In places, they overlap steep bedrock slopes or cliffs, thereby giving the impression of having even higher fronts.

Most of the moraines have a relatively mature aspect, owing largely to a mantle of locally derived colluvium or of eolian sand and silt. Boulders are relatively abundant on the surface, however, especially along morainal crests; many are fractured, but few are deeply disintegrated. No striated boulders were observed.

The ground moraine ranges from 30 to 60 feet in thickness, though in places, as in the valley of La Sal Creek, rounded bedrock knobs project through it. Kettles are rare, but some are as much as 30 feet deep. Most of the kettles are dry or marshy, and no peaty deposits were found in them.

Surface drainage of the till is fairly well integrated. Trunk streams have dissected the ground moraine to depths as great as 50 feet in many places, and have cut narrow channels through most terminal moraines. No natural lakes are retained by the moraines, though deposits of small ancient lakes were found back of a few of them. Artificial lakes are impounded by dams at terminal moraines of the upper member of the formation in Blue Lake Canyon and on Placer Creek.

The till of the Placer Creek formation is much more bouldery than that of the Harpole Mesa formation. In the upper parts of some canyons it is in fact an accumulation of tightly wedged blocks; and boulders and cobbles make up about 30 percent of the till in most terminal moraines. The fragments in the till are mostly angular slabs and blocks, but in the lower segments of canyons many have a soled, snubbed, or faceted shape. Very few striated fragments were noted. A few deeply weathered stones occur throughout the deposits. The matrix is commonly a compact arkosic sandy silt, but in areas underlain by shale it is clayey.

ALLUVIAL GRAVEL

Some alluvial gravel of the Placer Creek formation is preserved in nearly every major canyon, but it is considerably less widespread than similar deposits of the Harpole Mesa formation. In the mountains, it forms outwash plains that slope steeply away from their associated moraines; in the canyons, it underlies small isolated terrace segments or, locally, a pair of segments, one above the other. In the broader valleys, such as those of Pack Creek and La Sal Creek, it caps two fairly continuous outwash terraces (pl.5), and in Castle Valley it forms an extensive compound fill.

Alluvial gravel deposits of the Placer Creek formation have smooth regular surfaces that are commonly strewn with boulders and cobbles but are locally mantled by eolian sand and silt. In places, they retain shallow braided channels. Most of them are little dissected by secondary arroyos. Where the gravel deposits head at moraines, the surface gradients range from 600 to 1,200 feet per mile, flattening downstream to 200 to 100 feet per mile in the lower valleys and to only about 30 feet per mile along the Colorado River. Where the gradients are very steep, as along Pack Creek or Placer Creek, the surface locally slopes to one side of the valley as well as downstream, the difference in elevation on opposite sides of the valley being as much as 50 feet in some places.

Most of the deposits are from 15 to 30 feet thick, though some are as much as 60 feet thick, and those near Pinhook along Placer Creek are probably much thicker. The gravel is poorly sorted, crudely bedded, and has an arkosic sandy matrix. Boulders are abundant, particularly near moraines. Lenses of bedded sand or sandy silt are interbedded in the larger valleys and along the Colorado River. In the headwater areas, the gravel is largely composed of diorite, but downstream it includes more locally derived sandstone and shale, and along the Colorado River it contains much granite, gneiss, schist, basalt, and other rocks from outside the area.

The alluvial gravel of the Placer Creek formation can be subdivided into members in many places where the deposits grade into till. In Castle Valley and in Spanish Valley the lower member is separated from the upper by the Porcupine Ranch soil. Where the alluvial gravel caps two distinct terraces, the deposits of the higher terrace are inferred to belong to the lower member and those of the lower terrace to the upper member. The strongly developed profile of the Lackey Creek soil, developed on both members, masks any previously existing profile of the Porcupine Ranch soil on the lower member. The Lackey Creek soil is developed on eroded slopes of the lower member on the higher terrace but was not observed on eroded slopes of the upper member on the lower terrace.

ALLUVIAL SAND AND SILT

Alluvial sand and silt of the Placer Creek formation forms shallow fills in many valleys on the south flank of the mountains, where it appears to be derived from eolian deposits of the formation with which it interfingers. Other deposits cap and interfinger with the alluvial gravel of the formation in the large valleys west of the mountains.

The deposits consist of irregularly bedded fine sand and silt in variable proportions. Those which interfinger with or can be traced into outwash are clearly of glacial age. Those capping alluvial gravel or interfingering with eolian deposits may be of either late glacial or interglacial age. All the deposits are included in the Placer Creek formation because they are older than the Lackey Creek soil. Only very locally could they be related specifically to either the lower or upper member of the formation.

ALLUVIAL-FAN GRAVEL

Extensive deposits of locally derived angular alluvial-fan gravel occur along the sides of Castle Valley and Spanish Valley and form broad piedmont fans at the mouths of canyons on the south and northeast flanks of the mountains.

The deposits in general have a typical fan form. They average about 50 feet thick, though a few are as much as 100 feet thick. Most of them are poorly sorted and crudely bedded. Some, derived from cliffs, consist of slabby to blocky angular to subangular rock fragments, as much as 10 feet in diameter, in a matrix of sand, silt, and clay. Others, chiefly derived from gravel of the Harpole Mesa formation, contain much rounded gravel. The gravel in most of the deposits is composed of sandstone and siltstone, but that from the Harpole Mesa formation or from the higher mountains is mostly diorite. In general, fans on north-facing slopes are larger and less dissected than those on south-facing slopes. Dissection is greater at lower than at higher altitudes.

In a few places, notably in Spanish Valley, the deposits form compound piedmont fans in which both members are present. In Spanish Valley, the lower fan deposit grades eastward into outwash gravel of the lower member on a terrace 95 feet above Pack Creek; the upper fan deposit converges down arroyos cut through this terrace and grades into outwash gravel of the upper member on a terrace 50 feet above Pack Creek.

TALUS

Talus of the Placer Creek formation is extensively preserved in cirques that have not been glaciated since Placer Creek time, such as the south-facing cirques west of Mount Tomasaki (pl. 1), or in parts of cirques beyond the limits of Beaver Basin glaciation. It is also present along cliffs bordering the major canyons.

On the slopes of some cirques it is difficult to differentiate between talus and solifluction mantle of the Placer Creek formation. For purposes of mapping, the deposits have been considered to be talus if their slopes were even and concave, solifluction mantle if hummocky and convex.

In many places the talus grades into till and can thus be correlated. Elsewhere, the correlation is inferred from truncation by moraines or block rubble or overlap by talus of the Beaver Basin formation. In the lower parts of the area talus assigned to the Placer Creek formation grades into alluvial fans that in turn grade into outwash of the Placer Creek formation.

Talus that grades into till or outwash is clearly of glacial age, and theoretically most talus in the lower canyons probably developed during glaciation. However, cirque talus which does not grade into till may well be of late glacial or interglacial age, for frost action at high altitudes certainly outlasted glaciation. Talus is assigned to the Placer Creek formation wherever the Lackey Creek soil is developed on it.

In the mountains, the talus forms cones or compound cones that in places nearly bury the parental cliffs. Most of the cones are covered by dense forest, meadow, or tundra vegetation. Along the lower canyons talus forms sheets on steep bedrock slopes at the base of cliffs. Most of the sheets are mantled by fine-grained, partly eolian material, so that they look less blocky than sheets of younger talus. The deposits are commonly gullied 5 to 30 feet deep, exposing angular, slabby to blocky, coarse to fine rock debris. Most of the material came from cliffs above and is either structureless or crudely bedded parallel to the slope. Except where it grades into till of the upper member, the talus of the Placer Creek formation cannot be assigned to members.

SLOPE-WASH MANTLE

Slope-wash mantle of the Placer Creek formation forms a widespread but irregular veneer over the slopes surrounding the mountains below the limit of solifluction mantle of the formation. Deposits were mapped only where they are relatively thick and extensive.

The deposits occur on steep to gentle slopes and have smooth surfaces that locally preserve shallow rill channels. They range from a veneer to a layer about 6 feet thick and are thickest at their lower extremities. Some are structureless; others display a weak discontinuous bedding. Most of the deposits consist of small angular rock fragments in a matrix of sand, silt, and clay, but cobbles and large blocks are scattered through some. Rounded material is commonly derived from older gravel. No evidence was found to subdivide slope-wash mantle of the Placer Creek formation into members.

SOLIFLUCTION MANTLE AND FROST RUBBLE

Solifluction mantle and frost rubble of the Placer Creek formation are widespread on nonglaciated uplands and valley slopes (pl. 1). Their lower limits extend from 7,000 to 8,000 feet altitude on the west side of the mountains and from 8,000 to 9,500 feet on the east side.

The two kinds of deposits are mapped as a single unit because vegetation and inadequate exposures inhibit their ready differentiation. Their assignment to the Placer Creek formation is based on abundant downslope gradations into till, outwash, or alluvial-fan gravel or slope wash of the formation, and, like these other facies, the Lackey Creek soil development.

A few deposits can be related to specific members of the formation. At the southeast base of Mount Peale, the outer of a pair of large lobate solifluction masses, nested one upslope from the other, grades into a lateral moraine of the lower member of the formation, whereas the inner mass cuts across both the outer mass and the till of the lower member to grade into a lateral moraine of the upper member.

The deposits form sheets and lobate masses on slopes ranging from 5° to 45° with no cliffs and few rock exposures at their heads (fig. 23). They are characterized by hummocky surfaces exposing numerous blocks. Individual lobes are commonly 2 to 5 feet high, though some large forms below steep slopes have fronts as much as 20 feet high. Many terminate against streambanks. The deposits are commonly gullied 5 to 10

FIGURE 23.—Solifluction mantle of the Placer Creek formation, having an undulating surface slope of between 35 and 40 degrees, at an altitude of 11,800 feet on the north side of Miners Basin.

feet deep, but locally, as in Lackey Basin, gullies have been cut through 50 feet of solifluction mantle and 5 to 10 feet into bedrock.

The solifluction mantle consists of coarse and fine angular rock debris in an abundant matrix of sand, silt, and clay. Its color is commonly reddish, owing to its partial derivation from the B horizons of the Spring Draw soils. Most deposits are structureless, but some are involuted, and in others slabby fragments crudely parallel the slope.

Frost rubble includes masses of angular rock fragments that range from 6 inches to 3 feet in diameter. They occur on both steep and gentle slopes (fig. 24) and lack cliffs or ledges at their heads. Some deposits derive from older unconsolidated mantle which they abruptly contact; others grade downward into fractured bedrock. Interstices are void except near the surface, where they are filled with eolian or inwashed fines. Locally, on steep slopes fragments are imbricated, but no other structures were observed.

EOLIAN SAND AND SILT

Eolian sand and silt of the Placer Creek formation is widespread on the south side of the mountains and on the plateau surfaces west and north of them. Elsewhere the material forms only a thin, discontinuous mantle, mostly between 7,500 and 9,000 feet. Below this, the

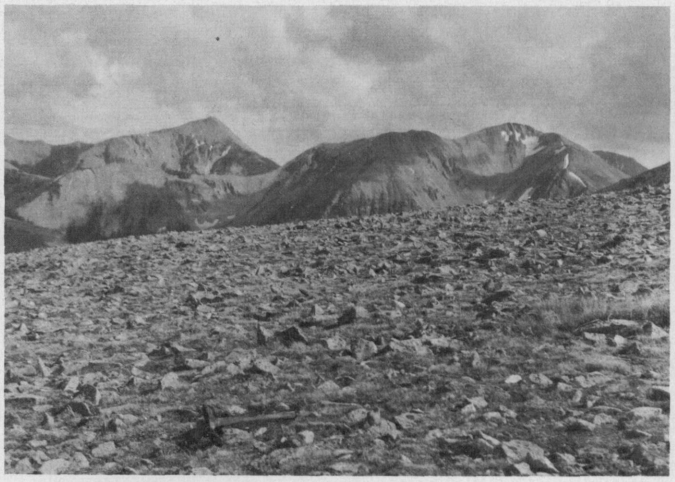


FIGURE 24.—Typical frost rubble sheet of the Placer Creek formation, on which the Lackey Creek soil is developed, covering gentle summit area of ridge northeast of Mount Waas.

material appears to have been largely reworked by later eolian activity; above, a few patches of it are preserved in the lee of ridges up to 11,500 feet. Some deposits are interlayered with alluvial-fan gravel that grades into outwash of the Placer Creek formation, and are clearly of glacial age; at other places the material is interlayered with alluvial sand and silt or lies conformably on outwash, till, or solifluction mantle of the formation, and here it may be of either late glacial or interglacial age.

The eolian deposits form irregular sheets that range from a veneer to layers as much as 15 feet thick. The thickest deposits are on the lower southwest flank of the mountains. No distinct dunes were seen, but dunelike accumulations are common on north and northeast-facing slopes cut in the Harpole Mesa formation, as on Amasas Back, south of Pack Creek (fig. 17*F*). The material is mostly well sorted and ranges from fine-grained sand at lower altitudes to silt in the higher mountains. Some deposits are structureless, and others have channel-and-fill crossbedding. The particles are mostly subround to subangular; a few are well rounded and frosted. Quartz makes up as much as 90 percent of many deposits. Feldspar and mafic minerals are present in variable amounts, but they are especially abundant in deposits in the mountains.

Some of the eolian deposits can be related to specific members of the formation. For example, on the south side of Spanish Valley, about 2 miles southeast of Moab, eolian deposits, on which the Porcupine Ranch soil is developed, rest on alluvial-fan gravel of the lower member and are overlain by alluvial-fan gravel of the upper member, capped by eolian sand which bears the Lackey Creek soil.

PORCUPINE RANCH SOIL

DEFINITION AND TYPE LOCALITY

The Porcupine Ranch soil is here defined as the relatively weakly developed zonal soil locally developed on the lower member of the Placer Creek formation. It is only recognizable where it is overlain by the upper member. Presumably it was originally developed on all deposits of the lower member, but, where not buried by the upper member, it was later masked by the more strongly developed Lackey Creek soil. It may not have superposed a recognizable effect on Spring Draw soils, but, though not so recognized, probably formed on exposed deposits from which a Spring Draw soil had been stripped. Nowhere was it recognized on bedrock.

The type locality of the Porcupine Ranch soil is in the north bank of Placer Creek, 100 yards upstream from Porcupine Ranch (SW¼SW¼ sec. 36, T. 25 S., R. 23 E.). Here it is developed on alluvial gravel of the lower member of the Placer Creek formation, and it is overlain by alluvial gravel of the upper member (fig. 25). On either side of the exposure, the Porcupine Ranch soil is cut off by a disconformity, which separates the lower and upper members of the formation but is hard to identify except where the soil is present.

This soil, though found at few localities, displays at each a similar development and geologic position beneath deposits that bear the Lackey Creek soil. The deposits on which it is formed either lie in valleys that dissect the Spring Draw soil, as at Porcupine Ranch, or overlie that soil, as in Fisher Valley north of the mapped area.

The Porcupine Ranch soil appears to mark an interval of nondeposition and essential slope stability following deposition of the lower member of the Placer Creek formation. It is cut by a disconformity indicating erosion before the upper member of the formation was deposited.

FACIES OF THE PORCUPINE RANCH SOIL

The Porcupine Ranch soil has been recognized in only two facies (fig. 19). A Brown soil facies ranges in altitude from 5,800 to 6,800 feet in Castle Valley and from 5,400 to 5,800 feet in Fisher Valley. These altitudes do not represent lower and upper limits but merely limits of known exposures. A Sierozem facies was found at altitudes between 4,200 and 4,700 feet in Spanish Valley; again the full range is unknown. Diagrammatic profiles of these facies are shown in figure 26. Both facies are relatively weakly developed compared with similar facies of the older Spring Draw soils, or of the younger Lackey Creek soil.

FIGURE 25.—Type locality of the Porcupine Ranch soil. Exposure is in the north wall of Placer Creek, just upstream from Porcupine Ranch. The relatively strongly developed Lackey Creek soil at the surface is formed on alluvial gravel of the upper member of the Placer Creek formation (*Qpau*). This gravel disconformably overlies the relatively weakly developed Porcupine Ranch soil formed on alluvial gravel of the lower member of the formation (*Qpal*). Details of the profile of the Porcupine Ranch soil are shown in figure 27 and in section 10, p. 108.

BROWN SOIL FACIES

A Brown soil facies of the Porcupine Ranch soil is exposed on gravel composed mainly of diorite at the type locality, at two other localities farther down Placer Creek, and in the north wall of Cane Hollow half a mile below the crossing of the road to Porcupine Ranch (fig. 27). It is also extensively exposed on eolian sand and silt in the badlands at the head of Onion Creek in Fisher Valley north of the mapped area. A typical profile developed on gravel is given in section 10.[4]

A disconformity at the top of the profile of the Brown soil facies suggests that its A horizon was stripped by erosion before burial. The B horizon ranges in thickness from 6 to 24 inches (table 9, p. 42). It is reddish brown (5*YR* 5/4) to brown (7.5*YR* 5/4), and its structure is consistently weak, medium to fine, angular to subangular blocky. The material is nonplastic to plastic and shows very little clay enrichment. The reaction (pH) ranges from slightly acid to neutral (6.5–7.2). The boundary between the B horizon and Cca horizon is commonly abrupt and irregular.

The Cca horizon ranges in thickness from about 12 inches on fine-grained materials to as much as 30 inches on coarse-grained materials (table 9). It is pink (7.5*YR* 7/4) to light brown (7.5*YR* 6/4). Carbonate is concentrated as streaks and lenses along bedding planes, joint planes, root casts, or other openings, and it thinly coats the rock fragments. The matrix is commonly very friable and nonplastic. Its reaction (pH) ranges from mildly to moderately alkaline (7.4–8.0). Krotovinas, filled with material from the B horizon, are relatively abundant.

[4] Sections referred to throughout the text are given under "Stratigraphic Sections of Soils."

SIEROZEM FACIES

A Sierozem facies of the Porcupine Ranch soil is exposed in a compound alluvial fan on the south side of Spanish Valley about 2 miles south of Moab. The soil is developed on eolian sand and silt which rests on angular fan gravel of the lower member of the Placer Creek formation. It is overlain by angular fan gravel of the upper member.

Though the soil was stripped from much of the lower member before the upper member was deposited, remnants are locally preserved. The profile is described in section 11 and in table 10, p. 43.

SUMMARY OF GENERAL CHARACTERISTICS OF THE PORCUPINE RANCH SOIL

The Porcupine Ranch soil is not widely enough exposed to disclose its character through a broad range in altitude. However, its B horizon averages less than 1 foot thick at about 6,100 feet and less than 6 inches thick at 4,400 feet. Its reddish color appears chiefly inherited and only partly due to sesquioxide accumulation. Little noticeable illuviation of clay has taken place. The pH values of the B horizon are nearer that of the parent deposit than are those of the Lackey Creek of Castle Creek soils. The Cca horizon averages about 30 inches thick. Its brownish to pinkish color, friability, and abundant voids indicate little carbonate accumulation except as thin coatings on the rock fragments, in places only on their undersides.

EROSION SURFACE BETWEEN THE LOWER AND UPPER MEMBERS OF THE PLACER CREEK FORMATION

Between the deposition of the lower and upper members of the Placer Creek formation downcutting by streams ranged from almost none to as much as 75 feet.

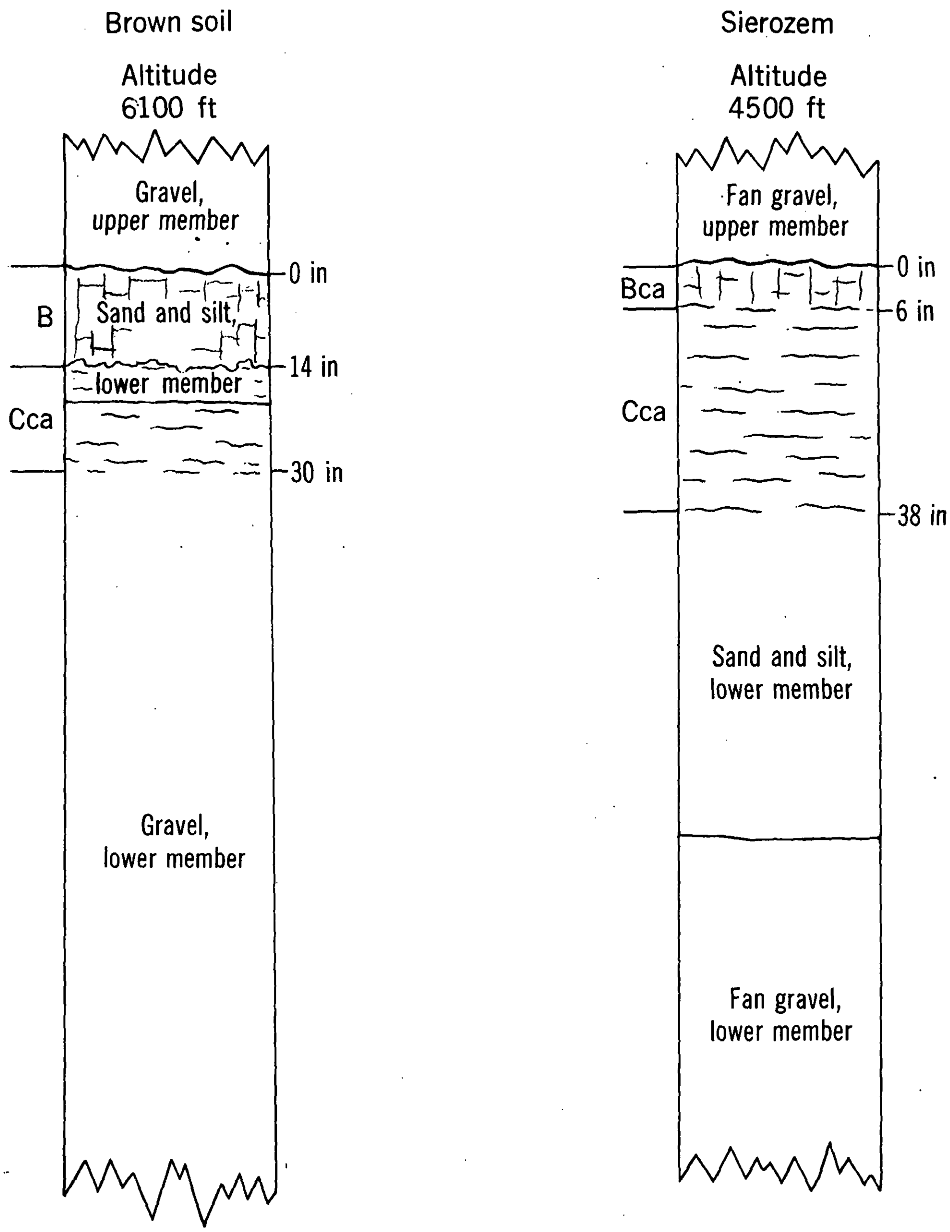


FIGURE 26.—Typical profiles of the two observed facies of the Porcupine Ranch soil showing, diagrammatically, their general character and thickness. The soil has been recognized only where it is developed on the lower member of the Placer Creek formation and is overlain by the upper member on which the Lackey Creek soil is developed.

In the mountains erosion was apparently very slight. Lower down, valleys cut at this time range from 15 to 30 feet in depth and from 50 feet to half a mile in width. In Castle Valley, alluvium of the upper member either rests conformably on the Porcupine Ranch soil or on a disconformity, with local relief of less than 15 feet, on the lower member. Where Pack Creek and Mill Creek enter Spanish Valley, however, gravels of the lower member were downcut 50 to 75 feet before gravel of the upper member was deposited (pl. 5).

LACKEY CREEK SOIL

DEFINITION AND TYPE LOCALITY

The Lackey Creek soil is a distinctive strongly developed zonal soil locally formed on the upper member of the Placer Creek formation, on the lower member where it is not buried by the upper, and locally on older deposits exposed at that time. Though seen in a few places where it is superposed on a Spring Draw soil, it could not commonly be so recognized. It was not observed on bedrock except in a few places on Mancos

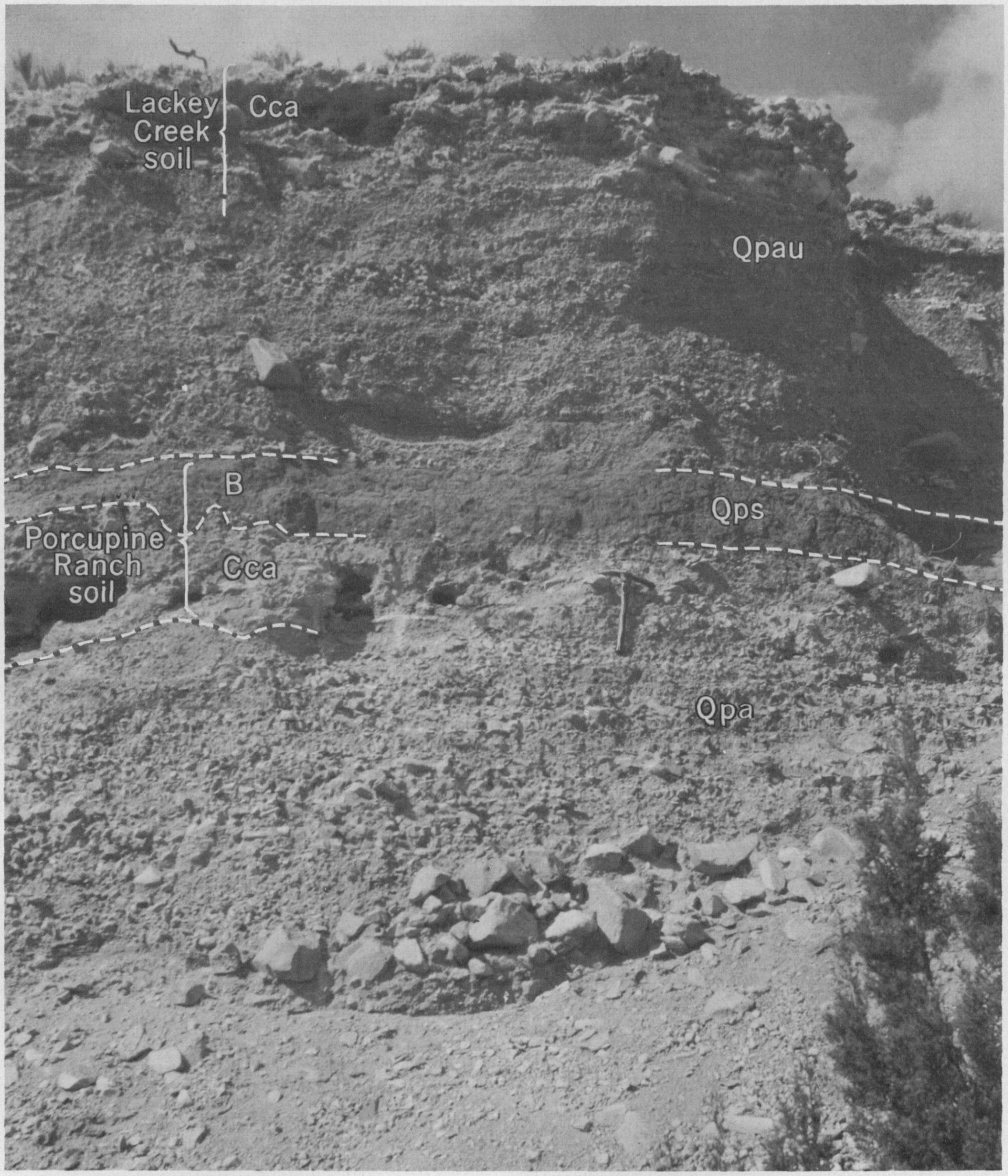


FIGURE 27.—Exposure of the Brown soil facies of the Porcupine Ranch soil on the north side of Cane Hollow one-half mile downstream from the crossing of the road to Porcupine Ranch (NE¼SW¼ sec. 25, T. 25 S., R. 23 E.). The Lackey Creek soil at the surface is developed on alluvial gravel (*Qpau*) of the upper member of the Placer Creek formation. This gravel rests disconformably on the Porcupine Ranch soil developed on alluvial sand and silt (*Qps*) and alluvial gravel (*Qpa*) of the lower member of the formation. Both gravels are included in one unit (*Qp*) on the geologic map (pl. 1).

shale. Examples of its stratigraphic relations are sketched in figure 17.

The type locality is on Lackey Creek, 2½ miles west of La Sal, just below the crossing of State Highway 46 (NW¼SW¼ sec. 4, T. 29 S., R. 24 E.), where the soil is developed on alluvial silt and fan gravel of the Placer Creek formation and is overlain by alluvial deposits of the Beaver Basin formation (fig. 28). The type section is described in section 21.

The Lackey Creek soil is formed on moraines of both members of the Placer Creek formation at their type localities, and can be traced from them to other deposits of the Placer Creek formation. Its absence on the lower member where it is buried by the upper,

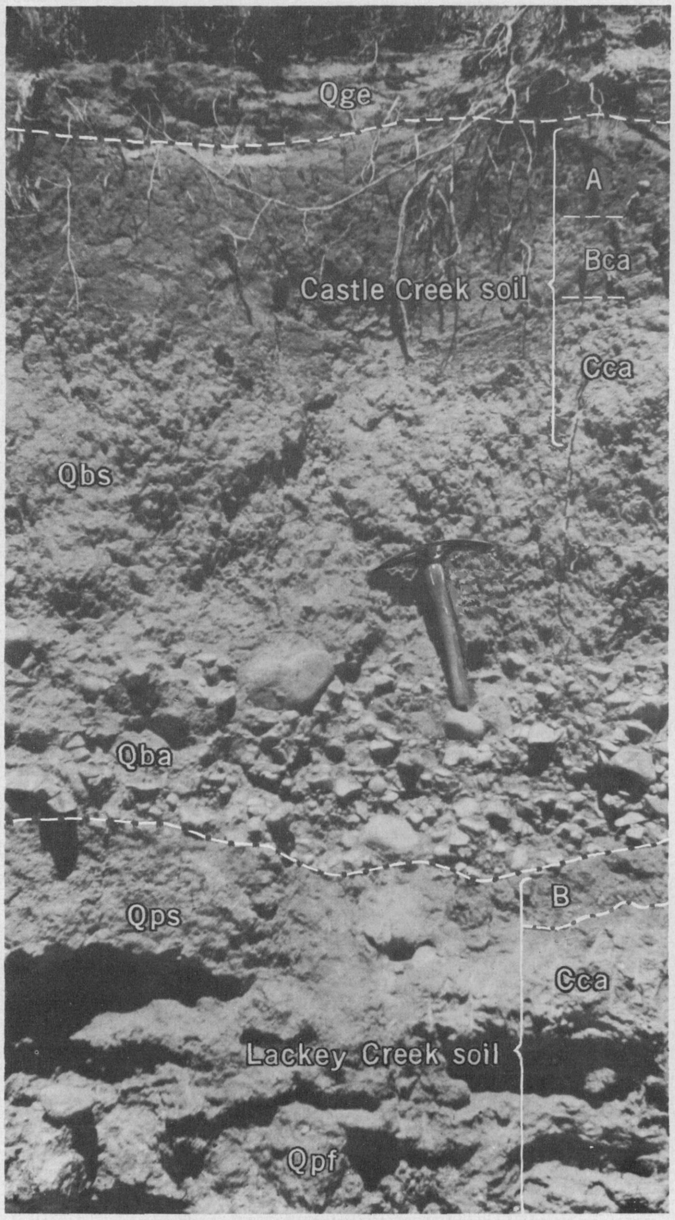


FIGURE 28.—Type locality of the Lackey Creek soil in the wall of Lackey Creek 2½ miles west of La Sal just downstream from the crossings of State Highway 46. The Brown soil facies of the strongly developed Lackey Creek soil is formed on alluvial silt (*Qps*) and fan gravel (*Qpf*) of the lower member of the Placer Creek formation, and is overlain disconformably by fan gravel (*Qba*) and alluvial silt (*Qbs*) of the Beaver Basin formation on which the moderately developed Castle Creek soil is formed. Recent eolian silt (*Qge*) overlies these deposits at the top of the section.

and the presence of the more weakly developed Porcupine Ranch soil at this horizon, clearly indicates that the Lackey Creek soil does not occur at two stratigraphic horizons. Its presence on the lower member where it is not overlain by the upper probably means that its stronger profile has masked the weaker profile of the Porcupine Ranch soil.

The relations of the Lackey Creek soil to the Beaver Basin formation are clearly exposed at many places. Some observed relations are sketched in figure 22. In each place, the Lackey Creek soil is either overlain by the Beaver Basin formation or is truncated by a disconformity overlain by that formation.

FACIES OF THE LACKEY CREEK SOIL

The Lackey Creek soil occurs as four distinct facies (pl. 2, fig. 19), each in a particular range in altitude. The four facies are a Brown Podzolic facies, a Brown Forest facies, a Brown soil facies, and a Sierozem facies (fig. 29). The soil can be traced continuously from one facies to the next up the mountains on the Placer Creek formation. Adjoining facies intergrade through a vertical range of about 200 feet. These relations are particularly well exposed along the road to Miners Basin in the valley of Placer Creek.

Each facies is less strongly developed than the corresponding one of the Spring Draw soils but more strongly developed than like facies of the Porcupine Ranch soil and of all younger soils.

BROWN PODZOLIC FACIES

The Brown Podzolic facies of the Lackey Creek soil is developed on the Placer Creek formation above a lower altitude limit ranging between about 8,400 and 9,200 feet, and an upper limit of 11,500 feet, the upper limit of the Placer Creek formation. The facies is developed on till, alluvial gravel, solifluction mantle, frost rubble, talus, and slope wash—all coarse textured and composed predominantly of either diorite or sandstone, though some consist largely of shale. Typical profiles are described in sections 12, 13, 14, 15, 16, and 17.

The Brown Podzolic facies is relatively constant everywhere. An A horizon was not observed in buried profiles. In relict profiles the structure and consistence of the A horizon so closely resemble those of younger soils and the color and reaction so closely follow the distribution of modern vegetation that the horizon is probably not part of the Lackey Creek soil.

The B horizon ranges in maximum thickness from about 4½ feet in the upper part of its altitude range to about 3 feet in its lower part (table 7, p. 39). Locally it appears slightly truncated. Its color is commonly yellowish red (5*YR* 5/6) to strong brown (7.5*YR* 5/6), but on mantle of diorite or Mancos shale the hue is 10*YR*. In general, the hue is less red than for Brown Podzolic profiles of the Spring Draw soils. As most deposits in the range of the Brown Podzolic facies are extremely coarse, the B horizon is commonly structureless, though locally, on eolian deposits or mantle derived from Mancos shale, it has a weak to moderate, fine to medium, angular to subangular blocky structure. The fine-grained material tends to be nonplastic in profiles developed on dioritic mantle, slightly plastic on mantle derived from sandstone, and plastic on mantle

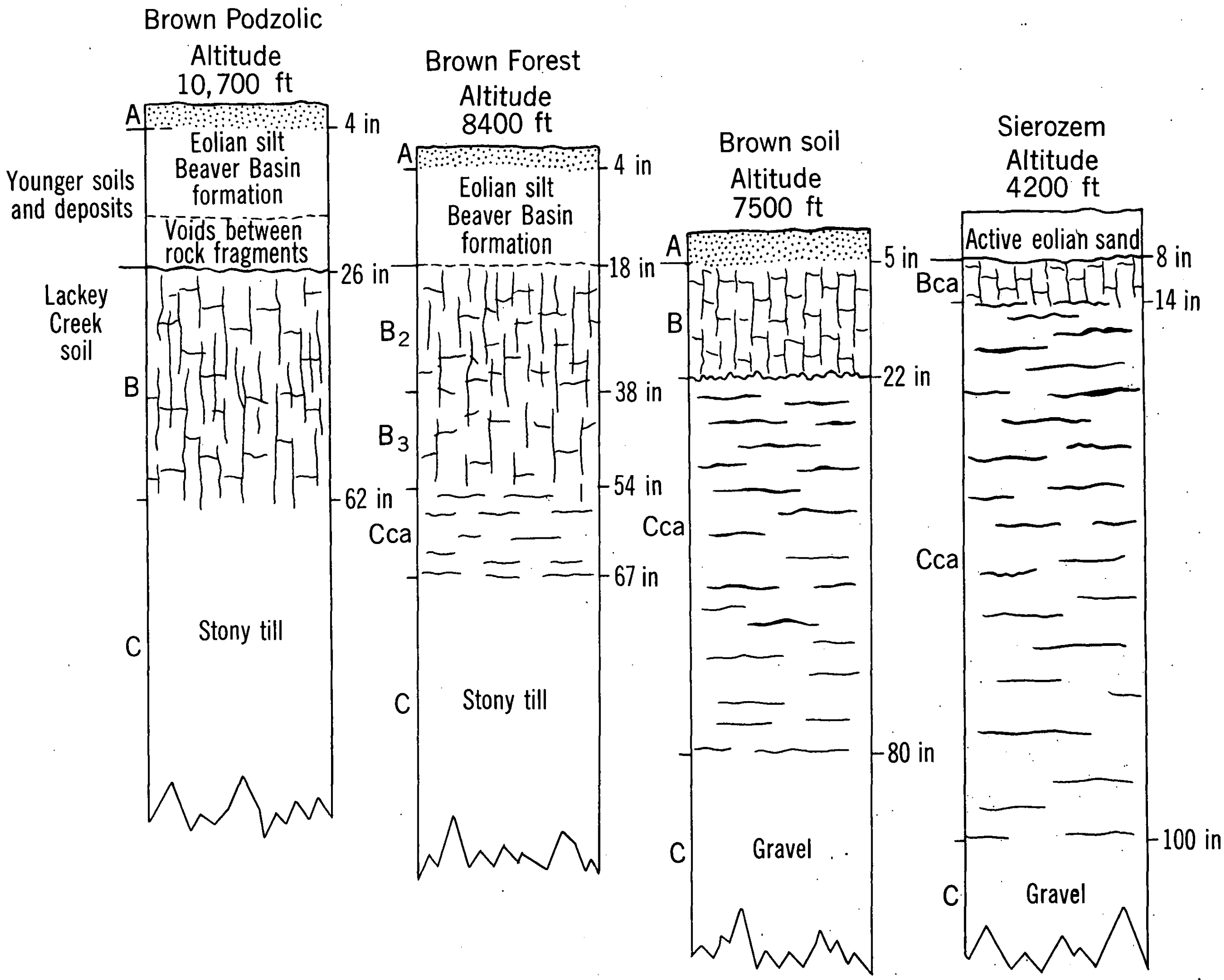


FIGURE 29.—Typical profiles of the four major facies of the Lackey Creek soil showing, diagrammatically, their general character and thickness on parent material composed chiefly of diorite.

derived from Mancos shale. Clay alluviation is generally discernible but not as markedly as in the Spring Draw soils on similar mantles. In profiles on mantle derived from sandstone, clay commonly coats individual grains in the B horizon. The reaction (pH) of the B horizon is very strongly acid (4.5–5.0) above an altitude of 10,500 feet strongly acid (5.1–5.5) between roughly 10,500 and 10,000 feet, medium acid between 10,000 and 8,800 feet, and slightly acid between 8,800 and 8,400 feet, the lower limit of the Brown Podzolic facies. Rotted fragments are no more abundant in the B horizon than in the underlying parent mantle.

BROWN FOREST FACIES

The Brown Forest facies of the Lackey Creek soil is developed on the Placer Creek formation between an upper limit ranging in altitude from 8,400 to 9,000 feet and a lower limit ranging from 7,400 to 7,800 feet (pl. 2, fig. 19). It is developed on coarse textured, poorly sorted till, solifluction mantle, slope-wash mantle, or alluvial gravel, and on eolian sand and silt; the soil profile on all is similar. The material, though mostly of diorite, is in places predominantly sandstone. Mantle derived from shale is scarce. Typical profiles are given in section 18, 19, and 20.

The Brown Forest facies of the Lackey Creek soil is relatively uniform. No A horizon was observed in buried profiles and that of relict profiles appears modified by the modern vegetation.

The B horizon has a maximum thickness ranging between 2½ and 3 feet (table 7, p. 39). It commonly consists or two components, an upper B_2 subhorizon that is yellowish red (5*YR* 5/6) to reddish yellow (7.5*YR* 6/6), and a lower B_3 subhorizon of a somewhat less red hue that is transitional into the Cca horizon. On mantle derived from sandstone the hue may be more red (2.5*YR*). The B horizon tends to have a weak to moderate, medium to fine, subangular to angular blocky structure and is less commonly structureless than that of the Brown Podzolic facies. It is slightly plastic to plastic and displays discernible clay accumulation, especially on eolian material or sandstone debris. The reaction (pH) ranges from slightly acid to neutral (6.1–7.0). Rotted fragments are no more abundant than in the parent mantle and much fewer than in the B horizon of the Brown Forest facies of the Spring Draw soils.

The Cca horizon ranges in thickness from about 1½ feet at an altitude of 8,400 feet to about 3 feet at 7,500 feet (table 8). In the upper part of this range, calcium carbonate forms thin films on the undersides of rock fragments, but it is not present in the matrix; at lower altitudes it thinly coats both fragments and matrix grains and forms local streaks and lenses. The color ranges from strong brown (7.5*YR* 5/6) at higher altitudes to very pale brown (10*YR* 8/3) at lower altitudes. The horizon is commonly structureless, but on fine-grained mantle it is locally weakly platy. The reaction ranges from neutral (7.0–7.3) at high altitudes to mildly alkaline (7.4–7.8) at lower altitudes and very locally to moderately alkaline (as much as 8.0) at the lowest occurrences of the soil. Krotovinas, filled with material from the B horizon, though rare, are present in places.

BROWN SOIL FACIES

The Brown soil facies of the Lackey Creek soil is formed on the Placer Creek formation between an upper limit ranging in altitude from 7,400 to 7,800 feet and a lower limit ranging from 5,500 to 5,800 feet (pl. 2, fig. 19). It is developed on dioritic alluvial gravel, on sandstone alluvial-fan gravel and talus, and on alluvial or eolian sand and silt. Typical profiles are given in sections 21 and 22.

The A horizon of buried profiles is as much as about 18 inches in thickness and is very dark gray (5*YR* 3/1 to 7.5*YR* 3/1). The material is commonly silty, has a weak to moderate, fine angular to subangular blocky structure, and is nonplastic and friable.

The B horizon ranges in maximum thickness from about 3 feet in the upper part of the altitude range to about 2 feet in the lower part (table 9, p. 42). Locally it includes a B_2 subhorizon that is brown (7.5*YR* 5/4) to reddish brown (5*YR* 5/4) and a somewhat lighter colored B_3 subhorizon. Profiles on mantle derived from sandstone or from the Morrison formation are reddest. The structure ranges from weak to moderate, fine to coarse subangular to angular blocky, or very locally columnar. The material is slightly plastic to nonplastic and shows discernible clay accumulation, especially in the B_2 subhorizon. Its reaction (pH) ranges from neutral to mildly alkaline (6.8–7.5).

The contact between the B horizon and the Cca horizon is in many places a sharp leached boundary.

The Cca horizon ranges from about 3 feet in thickness in the upper part of the altitude range of the facies to as much as 5 feet in the lower part (table 9). Carbonate coats both rock fragments and grains in the matrix, weakly cementing the material in many places. The color ranges from white (10*YR* 8/2) to light yellowish brown (10*YR* 6/4) and, on mantle derived from sandstone, commonly has a reddish hue (5*YR*). The horizon is structureless to strongly platy and its reaction (pH) ranges from moderately alkaline (7.9–8.4) in the upper part of the altitude range to strongly alkaline (8.4–9.0) in the lower part. Krotovinas, filled with material from the B horizon, are common in the Cca horizon.

SIEROZEM FACIES

The Sierozem facies of the Lackey Creek soil is developed on the Placer Creek formation below altitudes ranging from 5,500 to 5,800 feet (pl. 2, fig. 19). The facies is formed on alluvial gravel composed mostly of diorite, on alluvial-fan gravel and talus composed mostly of sandstone, and on alluvial or eolian sand and silt. A typical profile is given in section 23.

No A horizon was observed in buried profiles, and that on relict profiles appears to be mainly of younger origin.

A Bca horizon was observed locally. It ranges in thickness from 2 feet at higher altitudes to about 6 inches at lower altitudes (table 10, p. 43). Its color ranges from reddish brown (2.5*YR* 5/4) to brown (7.5*YR* 5/4), and it is structureless to moderately blocky. The material tends to be slightly plastic, and its reaction (pH) is commonly strongly alkaline (about 9.0).

The Cca horizon ranges in maximum thickness from about 5½ feet in the upper part of the altitude range to about 7 feet in the lower part (table 7). Its color is pinkish white (7.5*YR* 8/2) to light reddish brown (2.5*YR* 6/4). Calcium carbonate thickly coats rock fragments and thoroughly impregnates the interstices of the matrix, weakly cementing the material in places. The horizon is structureless to strongly platy and its reaction (pH) is strongly alkaline (about 9.0).

SUMMARY OF THE GENERAL CHARACTERISTICS OF THE LACKEY CREEK SOIL

Over the area as a whole, the Lackey Creek soil displays certain characteristics which set it apart from all others. These characteristics are those of well-drained profiles on relatively gentle slopes throughout the altitude range of the soil and apply to all facies.

The characteristics are as follows:

1. The average upper altitude limit of each of the four facies is not as high as that for similar facies of the Spring Draw soils, but it is higher than that of similar facies of all other soils in the area (fig. 19).

2. The B horizon ranges in maximum thickness from 6 inches at an altitude of 4,200 feet to 54 inches at 11,000 feet. At any given altitude it tends to be thicker than the B horizon of any other soil except the Spring Draw soils (fig. 28).
3. The hue of the B horizon ranges from 2.5*YR* to 10*YR*, generally from 5*YR* to 7.5*YR* (fig. 57*A*). This is less red than in the Spring Draw soils but redder than in any others.
4. The chroma of the B horizon ranges from 3 to 6 and is mostly from 4 to 5 (fig. 57*B*), thus it is commonly lower than in the Spring Draw soils but higher than in others. The color value ranges as in other soils (fig. 57*C*).
5. The structure of the B horizon ranges from columnar to subangular blocky, more commonly subangular blocky than in other soils (fig. 58*A*). The structure is in general less coarse and less strongly developed than in the Spring Draw soils but coarser and stronger than in any others (figs. 58*B*, 58*C*).
6. The material of the B horizon ranges from plastic to nonplastic, more commonly slightly plastic than in other soils (fig. 59). Illuviated clay is much less discernible than in the Spring Draw soils but more so than in others.
7. The reaction (pH) of the B horizon, excluding any Bca subhorizon, ranges from about 7.0 at an average altitude of about 5,500 feet to about 4.5 at 11,000 feet (fig. 60), thus averaging at any given altitude higher than in the Spring Draw soils but lower than in any others.
8. The Cca horizon ranges in maximum thickness from about 1 foot at 8,800 feet to about 7 feet at an altitude of 4,200 feet (fig. 61); thus, at any given altitude, it tends to be less thick than the Cca horizon of the Spring Draw soils but thicker than that of others.
9. The reaction (pH) of the Cca horizon ranges from about 7.0 at an altitude of 8,800 feet to about 9.0 at altitudes below 5,500 feet (fig. 60). At any given altitude above about 5,500 feet, the pH tends to be lower than in the Cca horizon of the Spring Draw soils but higher than in any others. Below about 5,600 feet, the pH is similar to that of the Spring Draw soils and greater than in others.
10. Although no quantitative measurements have been made, the Cca horizon at any given altitude probably contains more calcium carbonate than any soil except the Spring Draw sails.
11. In most places, the Lackey Creek soil appears to have been developed under well-drained conditions.
12. The Lackey Creek soil appears to have formed on relatively stable slopes, for the profiles on steep slopes are essentially the same as those on gentle slopes, though of course many profiles have been subsequently truncated. However, fully preserved profiles on steep slopes appear little different from those on gentle slopes.

EROSION SURFACE BETWEEN THE PLACER CREEK FORMATION AND THE BEAVER BASIN FORMATION

Stream erosion between deposition of the Placer Creek and Beaver Basin formations was considerably less than that following the Harpole Mesa formation. In a few places, as in southern Spanish Valley and lower Castle Valley, alluvial gravel of the Beaver Basin formation overlaps the Lackey Creek soil on the Placer Creek formation with almost no erosion. In most places, however, the Placer Creek formation was trenched before the Beaver Basin formation was deposited. Some erosion, mostly in the form of arroyos as much as 20 feet deep, preceded development of the Lackey Creek soil, as indicated by its local development on steep cuts in the upper member of the Placer Creek formation—for example, along upper Pack Creek and in the headwaters of East Coyote Wash.

Most of the erosion, however, is younger than the Lackey Creek soil. The deepest dissection appears to have taken place where Pack Creek and Mill Creek enter Spanish Valley (pl. 5), where alluvial gravel of the Placer Creek formation was trenched as much as 80 feet before deposition of alluvial gravel of the lower member of the Beaver Basin formation. Elsewhere, however, stream cutting resulted in channels 30 to 50 feet deep and 30 feet to half a mile wide.

BEAVER BASIN FORMATION

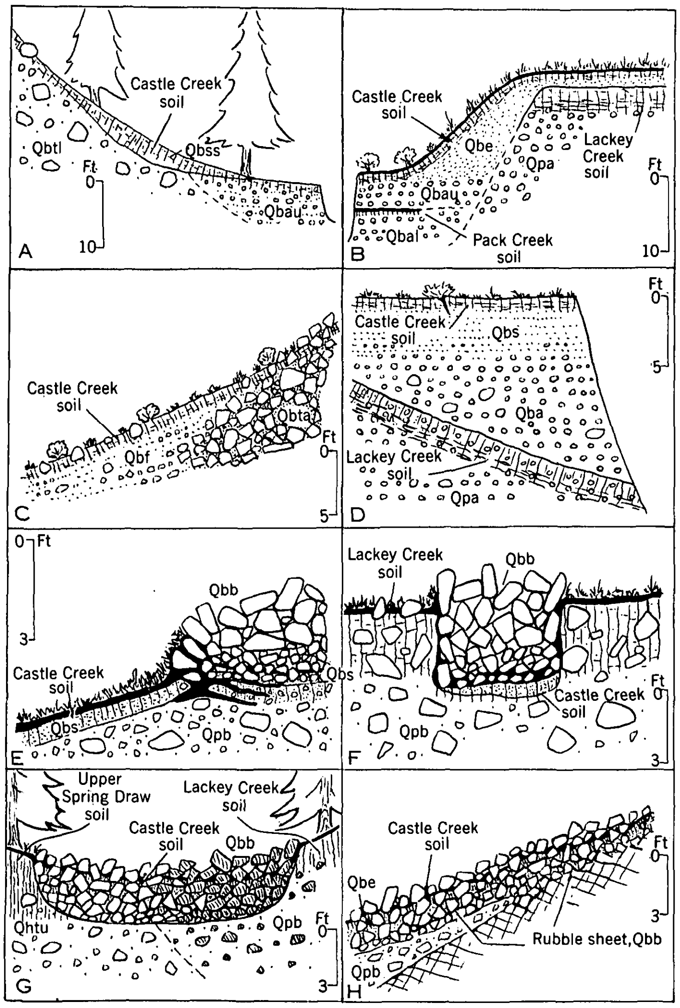
DEFINITION

The unit here named the Beaver Basin formation includes interfingering or intergradational deposits that overlie the Placer Creek formation or an erosion surface truncating it. In places it likewise disconformably overlies deposits older than the Placer Creek formation. The formation typically has the moderately developed Castle Creek soil on it (fig. 9), and is the youngest formation that bears this soil. It is commonly either overlapped or entrenched by deposits of the Gold Basin formation.

The Beaver Basin formation has two members. Where these are superposed, the upper bears the Castle Creek soil and the lower bears a weakly developed soil, the Pack Creek soil. Where not superposed, both members bear the Castle Creek soil, which apparently has masked the less well developed Pack Creek soil on the lower member. The Castle Creek soil, however, was rarely observed on older deposits, presumably because it is obscured by the preexisting and more strongly developed Lackey Creek and Spring Draw soils.

The Beaver Basin formation comprises 10 facies: till, rock glacier, alluvial gravel, alluvial sand and silt, alluvial-fan gravel, slope-wash mantle, talus, solifluction mantle, frost rubble, and eolian sand and silt (fig. 9). The two members of the formation can be distinguished in 6 of these facies, and in three they are sufficiently widespread to be mapped (pl. 1). Within each member, the facies interfinger or grade into one another over relatively short distances. Sketches of these relations at a few specific localities are shown in figure 30.

Similar facies of both members are much alike. They will therefore be described as a unit before discussing the evidence for subdividing them into members. The type area for the formation is defined on the basis of its till facies, to which all others are correlated.



A. Sketch of outwash gravel (*Qbau*) traceable from a moraine of the upper member of the Beaver Basin formation overlapping a lateral moraine (*Qbtl*) of the lower member of the formation. The Castle Creek soil is formed across the gravel, the till, and an intervening slope wash deposit (*Qbss*). Location: near site of mining camp in Gold Basin.

B. Sketch of gravel of the lower member of Beaver Basin formation (*Qbal*) on which the Pack Creek soil is developed, overlain by gravel of the upper member of the formation (*Qbau*). This compound fill lies in an arroyo that transects the Lackey Creek soil, developed on gravel of the Placer Creek formation (*Qpa*), and is overlapped by eolian deposits of the upper member of the Beaver Basin formation (*Qbe*) on which the Castle Creek soil is developed. Location: along West Coyote Creek above the junction of U.S. Highway 160 and State Highway 46.

C. Sketch of talus (*Qbta*) of the Beaver Basin formation merging into alluvial fan gravel (*Qbf*) of the formation. The Castle Creek soil is formed across both facies. Location: observed along several arroyos at the foot of the cliffs bordering the south side of Spanish Valley.

D. Sketch of alluvial gravel (*Qba*) of the Beaver Basin formation overlying the Lackey Creek soil on a disconformity truncating alluvial gravel (*Qpa*) of the Placer Creek formation. The deposit grades upward into alluvial sand and silt (*Qbs*) of the Beaver Basin formation on which the Castle Creek soil is formed. Location: in the north wall of Pack Creek at an altitude of about 8,400 feet.

E. Longitudinal section through the toe of a small rubble rill (*Qbb*) of the Beaver Basin formation developed from solifluction mantle (*Qpb*) of the Placer Creek formation. Section shows imbricate arrangement of blocks, outwashed silt (*Qbs*) and subjacent involuted humus layers. Location: south slope of summit of Manns Peak.

F. Cross section of a small rubble rill (*Qbb*) of the Beaver Basin formation, showing that it transects the Lackey Creek soil formed on solifluction debris (*Qpb*) of the Placer Creek formation from which the rubble is developed. The Castle Creek soil including the A horizon, is developed across fine material accumulated at the base of the rubble. Location: south slope near summit of Manns Peak.

G. Sketch of a rubble stream (*Qbb*) of the Beaver Basin formation developed along the contact between till of the upper member of the Harpole Mesa formation (*Qhtu*), composed mostly of diorite, and a solifluction deposit (*Qpb*) of the Placer Creek formation, composed wholly of sandstone. Note that the base of the rubble stream truncates both the Upper Spring Draw and the Lackey Creek soils, and that very little mixing of the contrasting rock types has taken place during its formation. Location: on south rim of Dark Canyon Creek at altitude of about 10,000 feet.

H. Sketch of a rubble sheet (*Qbb*) of the Beaver Basin formation, part of which is developed on bedrock, and part on older solifluction mantle (*Qpb*). The Castle Creek soil is formed on interstitial eolian sand (*Qbe*) which fills the interstices of the rubble sheet. Location: south slope of ridge east of Mount Tomasaki.

FIGURE 30.—Some stratigraphic relations of deposits of the Beaver Basin formation.

TYPE AREA

The Beaver Basin formation is named from Beaver Basin on the east side of the North Mountain group (pl. 1), where it is represented by two sets of moraines. Since no one exposure can be designated as a type section, Beaver Basin is designated as the type area. An outer moraine, representing the lower member, lies at an altitude of 10,050 feet at the mouth of the basin in a notch cut into the Lackey Creek soil that is developed on the upper member of the Placer Creek formation (fig. 31). Upstream, below each of the 11 cirques that rim the basin, are small bouldery end moraines, representing the upper member of the formation. Outwash from these moraines overlaps, or lies disconformably on, ground moraine of the lower member. Both sets of moraines bear the Castle Creek soil. Moraines of the upper member lie downstream from, or are overlapped by, younger moraines of the Gold Basin formation.

The two sets of moraines represent separate glacial advances, because wherever outwash gravel from them is superposed, as along Pack Creek on the southwest flank of the mountains (pl. 1), the deposits are separated by the weakly developed Pack Creek soil (fig. 40), whose character suggests that it formed under climatic conditions incompatible with the existence of local glaciers.

FACIES OF THE BEAVER BASIN FORMATION

TILL

Although absent from some canyons, till of the Beaver Basin formation forms two end moraines like those at the type area in the upper parts of most of them. A total of 34 moraines of the lower member and 45 moraines of the upper member were identified. The average altitude of moraines of the lower member is 10,270 feet, that of moraines of the upper member is 10,630 feet. In a few places, as on La Sal Creek. it is difficult to distinguish the terminal moraine of the upper member from recessional ridges related to the lower. Elsewhere, as on the south side of Miners Basin, the formation is represented by only a single moraine. In several canyons, either the upper or both moraines are represented by rock glaciers.

FIGURE 31.—Type locality of the till of the Beaver Basin formation in Beaver Basin on the east side of the North Mountain group. Till of the lower member of the formation (*Qbtl*) forms a terminal moraine in the canyon at the mouth of the basin. Till of the upper member (*Obtu*) forms terminal moraines below each of 11 cirques, not all of which can be seen in the photograph. Moraines of both members have the Castle Creek soil developed on them. They lie upslope from moraines of the Placer Creek formation (*Qptl* and *Qptu*) and downslope from small moraines of the Gold Basin formation, not obvious in the photograph, that lie beneath the cliffs in the cirques. *Opal* and *Opau*, alluvial gravels of the Placer Creek formation.

The moraines are relatively small and appear fresher and younger than those of the Placer Creek formation. Most of them are sharp distinct ridges with steep slopes. They average about 40 feet in height but range from 20 to 100 feet. A few, such as the moraine of the lower member on La Sal Creek, overlap steep bedrock slopes, thus appearing considerably higher. The slopes tend to be irregular and very bouldery. Individual boulders at the surface are commonly stained to depths of one-eighth to one-fourth of an inch. Few of the boulders are exfoliated or deeply rotted.

The rare kettles are steep sided. Some are as much as 30 feet deep, and many are occupied by ponds that dry up in summer. None contain distinct peaty deposits. Broad zones of kettles, as much as 200 yards wide, back of the end moraines of the lower member along La Sal Creek and Dark Canyon Creek, suggest that the glaciers may have stagnated near their termini during recession.

The ground moraine is dissected from 5 to 15 feet by those streams that head in cirques, and locally end moraines are breached by narrow gullies. However, few lake deposits were found back of moraines, and only two moraines retain lakes at present, owing presumably to the permeability of the till and the steepness of the terrain.

The till is more bouldery than that of the Placer Creek formation and somewhat less compact. High in the canyons, boulders comprise nearly all the till, particularly in lateral moraines. Most of the boulders are angular, though soled, snubbed, or faceted stones are abundant; striated fragments are rare. In the mountains, most fragments are diorite, but sandstone increases downstream. Rotted material is uncommon.

The matrix is friable and, except over shaly bedrock, is an arkosic silty sand.

ROCK GLACIER

Rock glaciers of the Beaver Basin formation occur at the heads of many canyons of the Middle and North Mountain groups, where they occupy the same position as end moraines in other canyons. Most of them lie below prominent cirques cut largely in diorite; a few relatively small ones, however, lie below sandstone cliffs along the sides of canyons, and possibly these should be considered protalus lobes, as defined on page 20. In eight canyons a pair of rock glaciers, representing both the lower and the upper members of the formation, are present (fig. 32); in five other canyons a rock glacier of the upper member lies upstream from a moraine of the lower member.

Rock glaciers of the Beaver Basin formation commonly overlap ground moraine of the Placer Creek formation and are locally overlapped by the Gold Basin formation. The deposits are inactive, and the Castle Creek soil is commonly developed on interstitial fine material a few feet below their surface.

The rock glaciers are lobate blocky masses having steep terminal snouts 30 to 75 feet high and flanks decreasing in height headward to the contact with the canyon wall. They range in length from 75 to 700 yards, measured from snout to overlap by younger deposits, and they may have originally been as much as a mile in length. They are 80 to 450 yards wide and differ in cross profile from slightly convex to slightly concave. Their terminal zones are characterized by arcuate ridges and furrows; and their headward zones are characterized by relatively smooth slopes that grade into talus at the cirque headwall. The headward zone is of course lacking where it has been reworked by younger rock glaciers, but none of the rock glaciers terminate abruptly headward in ice-contact slopes. This suggests that they did not form downvalley from a glacier, as has been observed by Capps (1910) and others in Alaska and inferred by Kesseli (1941) for some in the Sierra Nevada. Some rock glaciers have merely irregular hummocky surfaces. A few have kettlelike depressions containing water (fig. 33), and others have a series of short straight crevasselike furrows that project obliquely upstream from the borders of the deposits toward the centerline.

At the surface, the deposits consist mostly of angular blocks or slabs oriented at random. Individual blocks

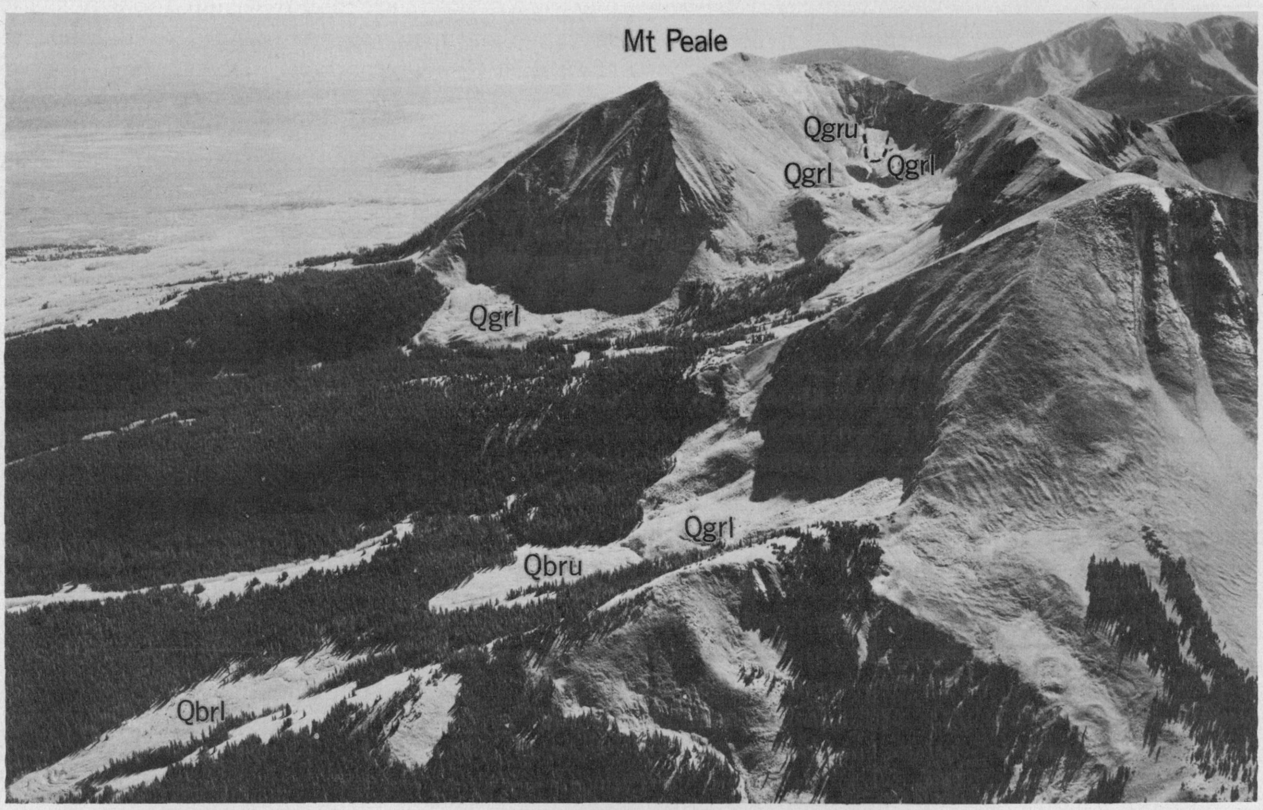


FIGURE 32.—Rock glaciers of the lower (*Qbrl*) and upper (*Qbru*) members of the Beaver Basin formation above Blue Lake northeast of Mount Mellenthin in the Middle Mountain group. A rock glacier of the lower member of the Gold Basin formation (*Qgrl*) lies upslope beneath the cirque headwall, and rock glaciers of both the lower (*Qgrl*) and upper (*Qgru*) members of the Gold Basin formation can be seen in the cirques to the south.

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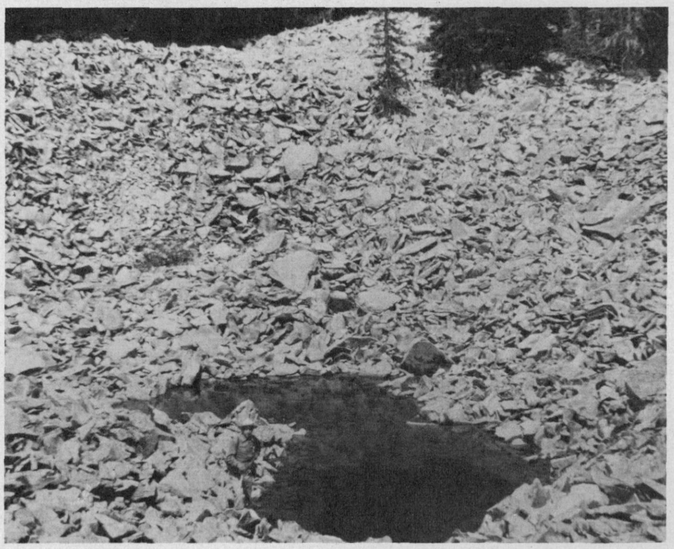


FIGURE 33.—A kettle in a rock glacier of the lower member of the Beaver Basin formation.

average from 1 to 3 feet in diameter but may be as much as about 15 feet. The blocky material differs in thickness and may locally include the whole deposit; but locally, both along the margins and at the surface, blocks lie in a matrix of unsorted sand, silt, and clay that looks like till. This material and the retention of water in the kettles suggest that a till core may underlie the blocky mantle.

The pairs of rock glaciers in some canyons clearly indicate two generations. The upper rock glacier overlaps and in places extends beyond the lower, leaving remnants of it to one side, and debris from the upper overlaps or lies in channels that dissect the lower.

That the pair of rock glaciers actually represent the upper and lower members of the formation is strongly suggested by the lack of moraines in canyons having a pair of rock glaciers and by single moraines in those with only one rock glacier.

ALLUVIAL GRAVEL

Alluvial gravel of the Beaver Basin formation is much less extensive than that of the Placer Creek, but it is more extensive than that of the Gold Basin. It tends to form narrow fills or terrace deposits trenched within alluvium of the Placer Creek formation. In places, however, as in parts of Spanish Valley and Castle Valley, it overlaps the Lackey Creek soil on the Placer Creek formation and occupies the full valley width. The deposits have the Castle Creek soil on them, and they are overlain or trenched by the Gold Basin formation.

In the higher mountains some small steeply sloping outwash plains or narrow outwash channel-fills grade into till of the formation. Below the moraines they form isolated terrace segments 10 to 30 feet above many streams. In the lower valleys they form a pair of terraces; deposits on the higher terrace are correlated with the lower member, and those on the lower are correlated with the upper member. In places these terrace deposits converge to form a compound fill in which the upper member, bearing the Castle Creek soil, overlies the Pack Creek soil on the lower member. Longitudinal profiles of the relations between such terraces and fills along Pack Creek are shown in plate 5.

The surfaces of the deposits are relatively smooth and commonly retain their original braided channels. Gradients range from as much as 1,200 feet per mile for short distances in the mountains to about 150 feet per mile lower down. Boulders and cobbles abound on the surfaces, though they are locally mantled by thin alluvial or eolian silt.

The gravel deposits are from 10 to 40 feet thick and consist of crudely bedded and poorly sorted, subangular to well-rounded, boulder gravel to cobble gravel. The gravel is chiefly of diorite, but it includes some sandstone and other rocks and, along the Colorado River, granite, gneiss, schist, and basalt from outside the area. The matrix is an arkosic to silty sand, of which lenticular layers are abundant at lower altitudes. Outwash deposits are mainly within a mile of the source moraine, and many appear trapped behind moraines of the Placer Creek formation. Downvalley, much gravel is derived from the Placer Creek formation, whose texture, particle shape, and other lithologic characteristics it closely reflects. In places, the material has obviously a very local source, for many cobbles well below the profile of the Castle Creek soil retain partly eroded calcareous coatings like those in the Cca horizon of the Lackey Creek soil nearby.

ALLUVIAL SAND AND SILT

Alluvial sands and silts of the Beaver Basin formation are much more widespread than those of the Placer Creek formation. They underlie much of the lower major valleys, especially Spanish Valley and Castle Valley, interfingering with alluvial gravel of both members of the formation. Such deposits are of glacial age. However, other extensive deposits, especially on the south flank of the mountains, intertongue with, and appear to represent a contemporaneous reworking of, eolian deposits, probably largely of interglacial age. In both situations, the alluvium is included in the formation because it is overlain by the Castle Creek soil. Many deposits form a compound fill in which the lower member with the Pack Creek soil on it is overlain by the upper member with the Castle Creek soil.

The smooth alluvial surfaces slope at gradients from 100 to 200 feet per mile. Most deposits are 10 to 15 feet thick but may be as much as 30 feet They consist of weakly bedded to massive, poorly sorted, pink to reddish-brown, fine sand and silt. Locally, they contain some clay, especially toward the top. The sand and silt are mostly of quartz, but in places feldspar abounds. Lenses of local gravel are common in the lower part of some deposits, especially in the lower member. Nodules and stringers of gypsum in the lower valleys presumably represent poorly drained ground. Small aquatic gastropods and pelecypods are rare; they are most numerous in clayey bands and in the uppermost layers across which the Pack Creek soil is formed. Scattered charcoal fragments in the upper member were insufficient for radiocarbon age determination; none were found in the lower member.

ALLUVIAL-FAN GRAVEL

Small fans of angular alluvial gravel border the larger valleys and occur at many canyon mouths. A few others are present below talus deposits in the high mountains. These fans are much less extensive than those of the Placer Creek formation.

Most of the fans head in gullies that dissect gravel of the Placer Creek formation, and they overlap that gravel downstream. They are themselves dissected by small draws containing alluvial fans of the Gold Basin formation. The Castle Creek soil overlies them. In many places they grade downslope into outwash gravel and headward into talus. A few fans grade into till or outwash gravel assignable either to the lower or the upper member of the formation, but most of them cannot be so related.

The deposits have smooth concave slopes, and most of them take the shape of individual fans rather than compound piedmont forms. Their surfaces are sparsely dissected by rather widely spaced gullies. Most of them are relatively thin, generally less than 40 feet thick, though in many places they are not fully exposed. The deposits are of poorly sorted, crudely bedded, angular gravel in a sandy silty matrix that is characterized by a shallow channel-and-fill crossbedding. The fragments are commonly of sandstone, but some are of diorite, many fragments of which may be rounded.

SLOPE-WASH MANTLE

Slope-wash mantle, which locally grades into other facies of the Beaver Basin formation and bears the Castle Creek soil, is widely scattered on steep to gentle slopes in the foothills and lower valleys. The deposits are only a few feet thick and consist of irregular sheets having smooth surfaces locally scored by shallow rills. Many of them consist of poorly sorted angular rock debris and fine-grained interstitial matter; though some are wholly of sand, silt, and clay. Some deposits display a weak discontinuous bedding, but most of them are structureless. No attempt was made to map this material.

TALUS

Talus deposits of the Beaver Basin formation are fewer and generally smaller than those of the Placer Creek formation. They are most prominent in cirques lacking rock glaciers or moraines of the Gold Basin formation, but they also border cirques beyond the outer limit of those deposits. Small deposits are abundant along most canyons and along the walls of Castle Valley and Spanish Valley. Generally, talus in the glaciated areas forms compound cones; elsewhere, it forms sheets on steep bedrock surfaces.

The deposits commonly overlap or entrench talus of the Placer Creek formation and are themselves overlapped or trenched by talus of the Gold Basin formation. They have the Castle Creek soil developed on their fine-grained interstitial matter, and locally they grade downslope into other facies of the Beaver Basin formation. Few are subdivisible as to member.

The talus consists of angular rock debris that range from chips to huge blocks but are mostly from 3 inches to 2 feet in diameter. In places it is crudely layered parallel to the slope. Fine-grained material, some of eolian origin, fills the interstices irregularly and locally forms the surface.

Most deposits have smooth concave slopes at angles as steep as 36°. A few have irregular, hummocky, or wavy surfaces that presumably result from localized movements of the material. Many deposits thin downslope to a featheredge, but in the mountains some terminate in a lobate mass bearing one or more arcuate ridges in which the fragments tend to be oriented imbricate to the slope. The snouts of the lobes are abrupt, and they are from 2 to 10 feet high. Such protalus lobes appear to have flowed slowly forward as a unit, presumably by solifluction. They are different from, but easily confused with, protalus ramparts (Bryan, 1934), which are ridges of randomly oriented rock debris accumulated at the toe of a talus by falling and sliding across perennial snowbanks at the foot of a cliff. Protalus ramparts have also been called winter talus ridges (Crawford, 1913; Behre, 1933).

Talus of the Beaver Basin formation is inactive. It supports little vegetation except where fine-grained matter is present at the surface. Rock fragments are sparsely covered with lichen.

SOLIFLUCTION MANTLE

Solifluction mantle of the Beaver Basin formation is confined to upland slopes above about 7,500 feet on the west side of the mountains and about 8,000 feet on the east side. The deposits are small and much less extensive than those of the Placer Creek formation which they commonly transect. All are inactive. Many grade into other facies of the Beaver Basin formation; all bear the Castle Creek soil. No criteria for distinguishing the lower or upper members of the formation in them were observed.

The deposits lie on slopes that range from less than 10° to more than 40°. They are sheetlike to lobate and have smooth to hummocky surfaces and local blocky concentrations. A few end in low ramparts, 1 to 3 feet high, but most grade into other facies or are cut off at gully banks.

The material is rarely more than 5 feet thick and consists of unsorted rock debris in a fine sandy to silty matrix. Humic bands are irregularly folded back under the terminus of many deposits. Blocky concentrations tend to occur along the arcuate crests of lobate masses or in discontinuous elongate shallow channels that trend irregularly downslope. Small areas of patterned ground also occur in a few places. Sorted polygons were observed on slopes under 8° and sorted stripes on steeper slopes.

FROST RUBBLE

Frost-rubble deposits of the Beaver Basin formation are much more widespread and distinct than those of the Placer Creek formation. They occur on slopes that range from nearly horizontal to as much as 42° on summit uplands, valley walls, and valley floors. Their lower limits range from an altitude of about 7,200 feet on the northwest flank of the mountains to about 9,000 to 9,500 feet on the east flank.

The deposits transect the Placer Creek formation (fig. 34) and grade into other facies of the Beaver Basin formation. Though many lack interstitial fines and hence display no soil development, many others contain at depths an interstitial filling of eolian or in-washed sand and silt on which the Castle Creek soil is formed (fig. 34). Deposits on the higher peaks are commonly overlapped by frost rubble of the Gold Basin formation.

All the frost rubble of the Beaver Basin formation is inactive. Blocks on the surfaces are lichen covered, and forest or tundra vegetation is encroaching on the borders. Springs issuing from the lower ends of the deposits are clear, even during seasonal thaws, and are eroding an "outwash" apron of bedded fine-grained material that borders the toes of some deposits.

In several places, as at the southeast base of Mount Peale, the southwest slope of Mount Tukuhnikivatz, and the northwest base of Mount Mellenthin, two lobate deposits of frost rubble are present, an inner deposit nested within and upslope from an outer deposit. That these two units may represent the lower and upper members of the formation is suggested by the nonparallelism of their lobate borders and by the

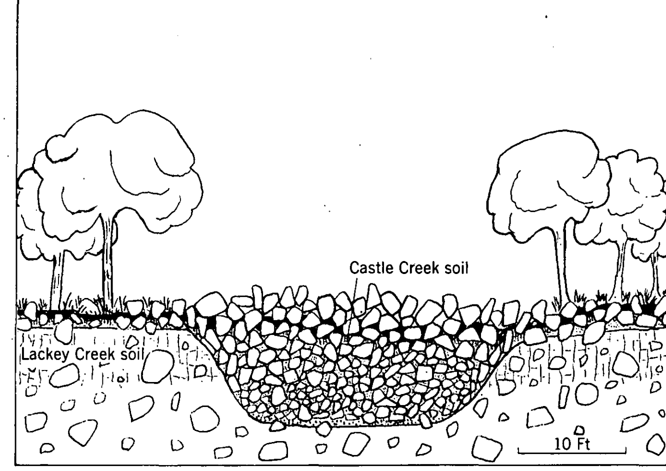


FIGURE 34.—Cross section of a rubble stream of the Beaver Basin formation developed on bouldery till of the Placer Creek formation along the road to Miners Basin at an altitude of 9,400 feet. The rubble stream truncates the profile of the Lackey Creek soil developed on the till. Some of the fine material, removed from the till during formation of the rubble stream, has settled at its base. Above, the interstices of the rubble were filled with eolian sand at some time after the rubble stream became stagnant. The sand is well sorted and composed almost wholly of quartz, in contrast to the poorly sorted and highly feldspathic character of the matrix of the till. The profile of the Castle Creek soil is formed on the eolian sand at a depth of from 2 to 4 feet below the surface of the rubble stream.

drainage channels that head along the edge of the inner deposit and transect the outer deposit.

The frost-rubble deposits consist of slabby to blocky angular rock fragments on slopes with no cliffs or prominent ledges above, thereby differing from talus (cliff detritus). The source is either subjacent bedrock (diorite or sandstone) or unconsolidated mantle. Individual fragments range from a few inches to a few feet in diameter.

As frost-rubble deposits have received but little study in the Rocky Mountains region, and as those of the Beaver Basin formation are extensively and distinctively developed, the several varieties (described on p. 19) observed will be described briefly here.

RUBBLE SHEETS

Rubble sheets are irregular deposits whose extent across the slope is greater than that downslope. They range in breadth from a few tens of yards to over half a mile. Most are only a few feet thick. These deposits, which have been called felsenmeer, block seas (block-mere), or block fields (blockfelden), include four genetic types: (1) frost-riven, developed in place from bedrock; (2) frost-creep, developed with slow downslope displacement on bedrock; (3) frost-sorted, developed in place from unconsolidated coarse and fine debris; and (4) frost-lag, developed with slow downslope displacement from unconsolidated coarse and fine debris.

Frost-riven rubble sheets.—The frost-riven rubble sheets occur on slopes ranging from a few degrees to as much as 10°. Their surfaces are characterized by randomly oriented, unsorted blocks, many on edge or on end, that grade down into fractured bedrock. Contacts between distinct kinds of bedrock show no significant net downslope displacement in the rubble. The deposits appear to be primarily the product of frost-riving and frost-shattering.

Frost-creep rubble sheets.—The frost-creep rubble sheets occur on slopes ranging from as little as 5° to as much as 42° (fig. 35). Typically, the fragments have moved down-slope, either individually or as localized masses. The surfaces of the deposits may be even or characterized by lobes or waves, the latter commonly oblique to the slope. A low rampart may be present along the lower edge.

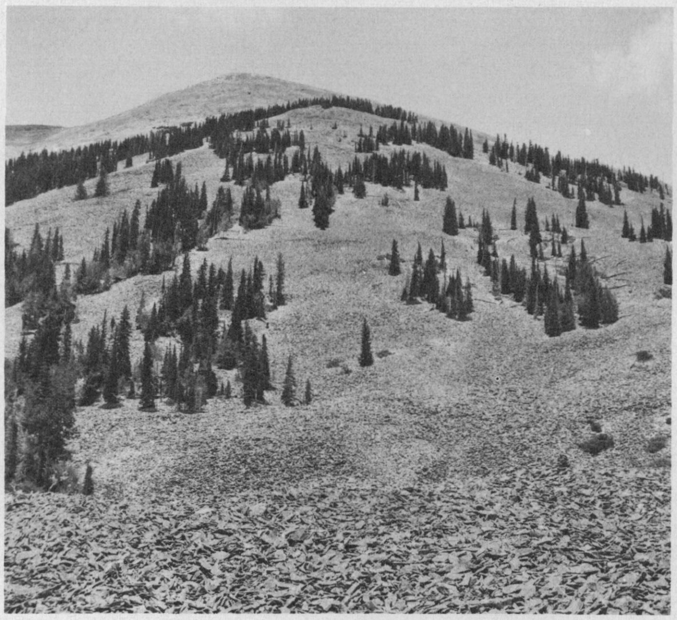


FIGURE 35.—Rubble sheet of the Beaver Basin formation mantling the south slope of Mount Peale.

Fragments on the surface are mostly oriented at random, but along the outer margins of lobes or of the terminal rampart the fragments may be imbricate to the slope. On slopes over 35° or on lesser slopes where the fragments are mostly slabby, the slabs tend to parallel the slope.

The deposits are crudely sorted from coarse to finer downward and rest disconformably on fractured bedrock. They appear to result from frost-shattering and frost-riving, accompanied by gravitative movements either alone or during thaw.

Frost-sorted rubble sheets.—Most frost-sorted rubble sheets occur on gentle slopes, though some are on slopes as steep as 15°. They develop from older unconsolidated coarse and fine debris. Blocks at the surface tend to lie at random. The borders are commonly abrupt, but in places they grade into areas of sorted polygons, rubble pits, reticulate rubble, and rubble rills. Locally they surround projections of the parent mantle or enclose isolated masses of coarse and fine debris known as "debris islands."

The rubble is mostly about 3 feet thick but may be as much as 10 feet thick. It abruptly transects the subjacent unconsolidated mantle from which it is derived. Most deposits are crudely sorted from coarse to finer downward and have a fine-grained layer at their base.

Four characteristics indicate that the deposits have not moved downslope: (1) they display no terminal rampart or other surface feature suggesting movement; (2) they display no preferred orientation suggesting movement; (3) no significant downslope displacement is seen where they cross contacts; (4) preexisting topographic features, such as moraines, are preserved in the form of the rubble.

Frost-sorted rubble sheets probably result from sorting in place by repeated freezing and thawing, accompanied during thaw by washing or sludging downward of the finer components. Some deposits may be in part the product of gradual destruction of areas of sorted polygons by these processes.

Frost-lag rubble sheets.—The frost-lag rubble sheets occur on slopes of 10° to 42° and are developed from unconsolidated coarse and fine debris. Their surfaces are even to irregularly hummocky. The headward areas tend to be marked by a shallow depression, and lower margins tend to be lobate. In places, the sheets grade into areas of irregularly anastomosing rubble festoons or rubble rills; but more commonly they end in an abrupt rampart 3 to 15 feet high. Along these ramparts, and to some extent along the downslope edge of surface hummocks, slabby fragments tend to be imbricated. Along the sides of the sheets, slabs tend to parallel the side and dip nearly vertical.

The deposits are as much as about 10 feet thick. They abruptly transect the unconsolidated debris below. Most of them are crudely sorted from coarse to finer downward with a layer of fine-grained material at their base and in an apron bordering the terminal rampart.

The observed downslope displacement ranges from a few yards to, in a few places, as much as 200 yards.

The deposits are believed to have formed through sorting of debris by repeated freezing and thawing and concurrent down washing of the fines. Downslope transport probably took place by settling of the blocks and by local solifluction of the debris beneath them.

RUBBLE STREAMS, LOBES, AND RILLS

Rubble streams, lobes, and rills are deposits whose downslope extent is greater than that across the slope.

FIGURE 36.—A rubble stream of the Beaver Basin formation on the southeast slope of Mount Peale. The rubble stream is about three-quarters of a mile long, and merges with a rubble sheet on the slope of the mountain to the left. The cliffs to the right of the mountain are at the head of a cirque that opens below the horizon to the right and are not the source of the rubble stream.

Rubble streams are large and, in places, sinuous forms as much as several hundred feet wide and over half a mile long (fig. 36). Rubble lobes are intermediate forms as much as about 300 feet wide and nearly as much in length. Rubble rills are small, narrow, and commonly sinuous forms as much as a few tens of feet wide and a few hundreds of feet long (fig. 37); most of them, however, are only a few feet across and a few yards long. Rubble rills differ from rubble stripes in that their arrangement with respect to each other is nonparallel; individuals do not necessarily parallel the direction of slope; and inter-rill areas were not sorted during rill formation.

All these deposits are developed from unconsolidated coarse and fine debris; none were observed on bedrock. Some are developed in place on gentle to moderate slopes and are apparently of frost-sorted origin; others, mostly on moderate to steep slopes, are developed with downslope movement and are apparently of frost-lag origin.

Frost-sorted forms.—Frost-sorted rubble streams, lobes, and rills are much alike except for shape, and they display the same criteria for lack of movement as frost-sorted rubble sheets, discussed above. Most of them lie at or just below the level of adjacent terrain, though some lie just above it near their terminus. Blocks at the surface are oriented at random and at depth are crudely sorted from coarse to finer downward. The deposits rest in abrupt contact on their subjacent source materials. All three varieties are commonly sharply demarked, but locally they grade into areas of rubble polygons, reticulate rubble, or rubble pits.

FIGURE 37.—Rubble rills and festoons of the Beaver Basin formation formed in solifluction deposits of the Placer Creek formation on the west flank of Mount Peale. The rubble deposits transect the Lackey Creek soil on the grass-covered solifluction slopes.

Frost-lag forms.—Frost-lag rubble streams, lobes, and rills have distinctive surface characteristics. Some stem from a single basin-shaped headward area; others stem from fingerlike or irregularly shaped headward areas that extend upslope from both the sides and upper end. Headward sectors are concave in cross-profile and have relatively smooth slopes. Middle sectors range from convex to concave and in larger forms tend to have hummocky surfaces. Frost-lag rubble streams are commonly marked by low longitudinal ridges separated by shallow, steep-sided furrows. Sinuous deposits tend to have lateral ramparts along the outer sides of bends and to lie below the level of adjacent terrain along the inside. Terminal sectors are typically convex except in forms extending from steeper onto more gentle slopes, where they may be concave. The shape of the terminus ranges from a pointed snout to a broad arc. All forms tend to end in abrupt terminal ramparts that are commonly 3 to 6 feet high, but in larger forms they may be as much as 30 feet high. Back of this rampart in frost-lag rubble streams are commonly a series of arcuate ridges and furrows having a local relief of 3 to 6 feet.

In all forms, surface blocks are mostly oriented at random, but those in terminal or lateral ramparts tend to be imbricate on the slope. Those along arcuate or longitudinal furrows or along borders parallel to the slope tend to be alined downslope with their slabby surfaces nearly vertical. In a few places at bends in the deposits, slabby fragments are oriented in shingled rosettelike fashion to produce a shallow concave swirllike structure. Elsewhere, particularly on slopes greater than 35°, they tend to parallel the slope.

The deposits are mostly 2 to 5 feet thick, though some rubble streams are as much as 30 feet thick. All transect and lie abruptly on subjacent coarse and fine debris. A basal layer of fine-grained material is common in some, and aprons of similar material border the terminal ramparts of a few.

The displacement of fragments in these frost-lag deposits is commonly only a few yards, but in some rubble streams it is as much as several hundred yards. The deposits, especially the rubble streams, tend to obliterate preexisting topographic forms which they cross, and where they cross the contact of two different deposits blocks from both deposits are mixed downslope from that contact.

Frost-lag rubble streams and lobes tend to be sharply demarked. Frost-lag rubble rills commonly grade into frost-lag rubble sheets or areas of rubble festoons (fig. 37).

RUBBLE FESTOONS

Rubble festoons are narrow loop- or arc-shaped deposits developed on moderate to steeply sloping solifluction mantle. They trend downslope, anastomosing irregularly in draperylike arrangement (fig. 37). The breadth of individual arcs, from tip to tip across the slope, ranges from a few feet to over 100 feet; the length, downslope from tip to toe, ranges from a few yards to over 50 yards. The width of the rubble at any point along the arc ranges from 3 to 30 feet, being widest at the toe. The deposits are from 1 to 5 feet deep and transect the solifluction mantle on which they lie. A preferred orientation of slabby fragments parallel to the sides and imbricate to the toe is common, suggesting that most deposits have moved downslope. They are believed to have formed by frost-sorting and washing, in most places during solifluction of the deposit on which they rest. They are therefore classed as frost-lag deposits.

FIGURE 38.—Reticulate rubble of the Beaver Basin formation formed on solifluction mantle of the Placer Creek formation. The rubble has the Castle Creek soil formed on it and transects the Lackey Creek soil developed on the grass-covered solifluction mantle.

RETICULATE RUBBLE

Rubble deposits, here termed reticulate rubble, occupy an irregular network of channels on gentle upland slopes and have been segregated in place from underlying unsorted coarse and fine debris (fig. 38). The channels range greatly in size and lack a regular pattern. They enclose irregularly shaped areas of unsorted debris which do not appear to have been affected by the sorting processes that segregated the rubble. For example, this material has the same texture as debris in adjacent areas where rubble is not developed. In these several respects, reticulate rubble differs from sorted polygons.

The channels of rubble are about 3 to about 15 feet wide and enclose areas 3 to 20 feet wide and 5 to 50 feet long. Where the slope steepens, they commonly grade into rubble rills or rubble festoons. The deposits are believed to be the product of frost-sorting and washing in place, but of a kind that did not lead to the development of a regular polygonal pattern enclosing sorted centers. Possibly the frost action was either of insufficient intensity or duration.

RUBBLE PITS

Rubble pits are small roughly circular masses of rubble in depressions, 3 to 6 feet in diameter, that occur on flat to gentle slopes near frost-sorted rubble sheets, reticulate rubble, or sorted polygons. They show no regular pattern. Some appear to have been developed in place from subjacent unsorted coarse and fine debris by a sorting or washing process. Others represent reopenings in a rubble sheet that had become filled or covered by fine-grained material.

RUBBLE POLYGONS

Rubble polygons occur on gentle upland slopes. Some near the summit of Mount Mellenthin are typical sorted polygons (Washburn, 1950) developed from unsorted coarse and fine debris. Others, near the summit of Mount Peale, are developed on bedrock by frost-shattering and frost-riving and have not been sorted.

The polygons range from 1 to 5 feet in diameter. Frost-sorted forms enclose circles of fine debris containing fewer stones than adjacent debris beyond the polygons. Frost-riven forms are rosettelike and some are stonecentered (Rozanski, 1943). Most of them are developed on shaly bedrock.

RUBBLE STRIPES

Rubble stripes occur on upland slopes ranging from 5° to 15°. Sorted stripes (Washburn, 1950) were observed at only 1 locality. In the saddle south of Mount Mellenthin, stripes of rubble, 6 to 12 inches wide, separate stripes of fine-grained debris 12 to 18 inches wide. The stripes are 6 to 8 inches deep and form a regular pattern parallel to the slope. Frost-riven forms composed of slabby fragments wedged together in a herringbone arrangement were observed on the north ridge of Mount Peale, where they are developed on calcareous shale of the Morrison formation. They have a regular pattern, trend parallel to the slope, and grade downward into bedrock. Most are 6 to 18 inches wide and 6 to 12 inches deep.

EOLIAN SAND AND SILT

Eolian sand and silt of the Beaver Basin formation is much less widely distributed than that of the Placer Creek formation. The largest deposits are west of the mountains in Spanish Valley, along West Coyote Creek, on the uplands west of Browns Hole, and on North Mesa and South Mesa. Other deposits on the plateaus east of Moab are mostly covered by younger eolian material. In the mountains, thin patchy accumulations occur as high as 12,500 feet.

The deposits consist of well-sorted fine sand at lower altitudes and of silt on higher slopes. They overlie the the Lackey Creek soil in many places. Some are interlayered with alluvial gravel of the Beaver Basin formation and appear to be of glacial age. Most, however, conformably overlie glacial deposits and are probably of interglacial orgin. All the deposits are included in the Beaver Basin formation because they have the Castle Creek soil on them. In most places they form a single stratigraphic unit, but in a few places they are compound, a lower unit bearing the Pack Creek soil overlain by an upper unit bearing the Castle Creek soil. The two units probably represent the lower and upper members of the formation. They are clearly exposed along a washed-out irrigation ditch on the south side of Burkholder Draw at the northeast corner of North Mesa (fig. 39).

At lower altitudes the eolian deposits form hummocky sheets suggesting low dunes and sand drifts; at higher

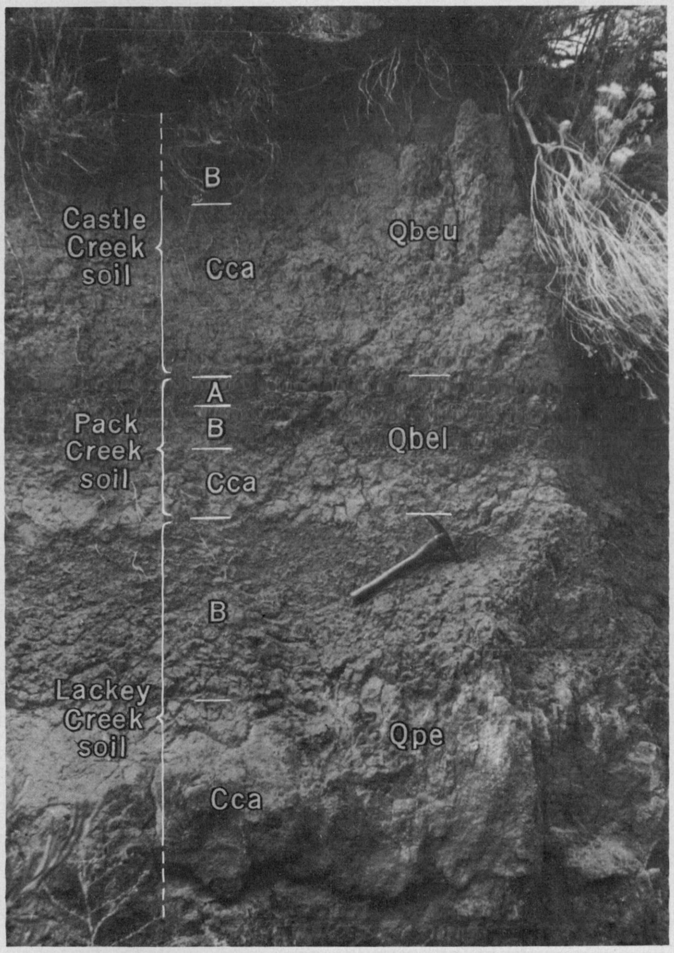


FIGURE 39.—Section in the wall of Burkholder Draw northeast of North Mesa. The Castle Creek soil at the surface is formed on eolian sand of the upper member of the Beaver Basin formation (*Qbeu*) which overlies the Pack Creek soil on eolian sand of the lower member (*Qbel*). These deposits rest on the Lackey Creek soil developed on undifferentiated eolian sand of the Placer Creek formation (*qpc*).

altitudes they tend to form thin lenses on lee slopes and in depressions or thin layers in the interstices of frost rubble. Most of the deposits are structureless, though some at lower altitudes are crossbedded. The material is mostly quartz, in places as much as 90 percent, but many deposits contain from 30 to 50 percent of feldspar and small amounts of mafic minerals.

PACK CREEK SOIL

DEFINITION AND TYPE LOCALITY

The Pack Creek soil is here defined as the weakly developed soil locally developed on the lower member of the Beaver Basin formation. Though its profile is commonly zonal, it is essentially azonal in places. It is only recognizable where overlain by the upper member, but presumably if was originally developed on all deposits of the lower member. Where not buried by the upper member, however, it was later masked by the more strongly developed Castle Creek soil. It probably did not superpose a recognizable effect on the preexisting Spring Draw and Lackey Creek soils, but, though not so recognized, it presumably formed on exposed deposits from which the Spring Draw or Lackey Creek soils had been stripped. Nowhere was it recognized on bedrock.

The Pack Creek soil is named from a type locality on Pack Creek just above the National Forest boundary (SW¼NE¼ sec. 31, T. 27 S., R. 24 E.). Here, it is a distinct marker within alluvial gravel of the Beaver Basin formation on which the Castle Creek soil is developed (fig. 40). The Castle Creek soil is overlain disconformably by gravel of the Gold Basin formation on which the very weakly developed Spanish Valley soil has formed. A section measured in the arroyo wall at the type locality is given in section 25.

The Pack Creek soil is extensively developed on alluvium of the Beaver Basin formation in the canyon of Pack Creek, in Spanish Valley, Castle Valley, Browns Hole, along West Coyote Creek, and on eolian sand and silt along a deep irrigation ditch on the south side of Burkholder Draw (fig. 39). At each of these localities it lies below the Castle Creek soil, and in several it is seen to be above the Lackey Creek soil. The Pack Creek soil can be traced for long distances, suggesting that it marks a widespread, though probably short, interval of essential nondeposition and slope stability within the Beaver Basin formation.

FIGURE 40.—Type locality of the relatively weakly developed Pack Creek soil at an altitude of 7,500 feet along Pack Creek. A Brown Forest facies of the soil is here developed on alluvial silt and gravel of the lower member of the Beaver Basin formation, and is overlain by alluvial gravel of the upper member of the formation on which the moderately developed Castle Creek soil is formed.

FACIES OF THE PACK CREEK SOIL

The Pack Creek soil occurs in four facies: a Brown Podzolic facies, a Brown Forest facies, a Brown soil facies, and a Sierozem facies (fig. 41). The Brown Podzolic facies is present above an altitude of 7,800 feet, the Brown Forest facies, between 7,800 and 7,000 feet, the Brown soil facies, between 7,000 and 5,100 feet; and the Sierozem facies, below 5,100 feet (fig. 19). These facies can be traced from one into the other. Along Pack Creek, each facies change takes place through an altitude range of about 200 feet.

BROWN PODZOLIC FACIES

The Brown Podzolic facies of the Pack Creek soil has been recognized only along Pack Creek, where, however, it can be traced almost continuously from an altitude of 7,800 feet to about 9,500 feet. A profile, measured at an altitude of about 8,500 feet, is given in section 24.

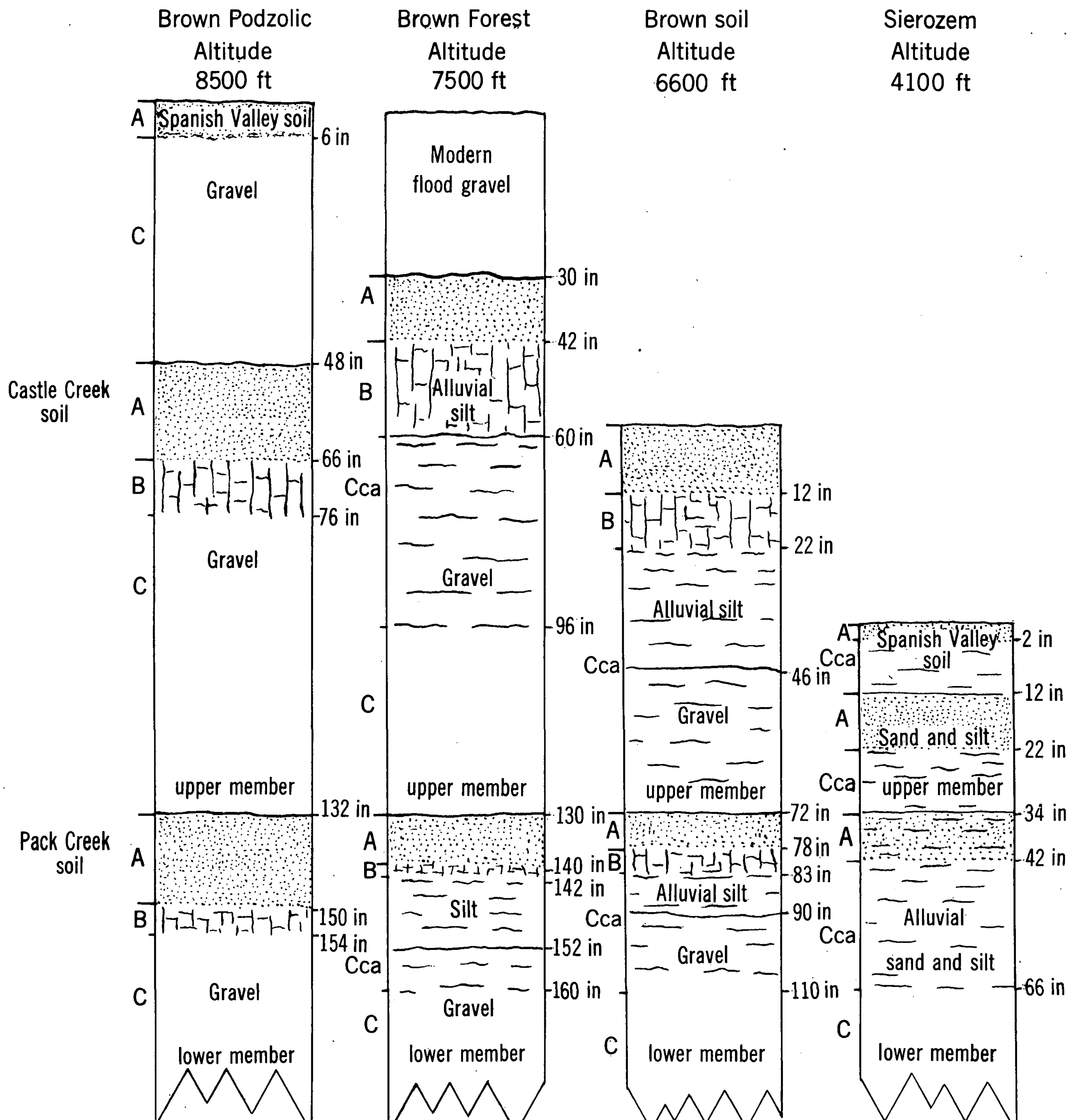


FIGURE 41.—Typical diagrammatic profiles of the four major facies of the Pack Creek soil, showing their general character and thickness. The Pack Creek soil is recognized only where developed on the lower member of the Beaver Basin formation and overlain by the upper member on which the Castle Creek soil is developed.

An A horizon is common in the buried profiles. It is 12 to 24 inches thick, dark gray (10*YR* 4/1) to very dark gray (10*YR* 3/1), and has a very fine to fine, angular to subangular blocky or granular structure. It is nonplastic to slightly plastic, conditioned by the parent mantle rather than soil-forming processes. The reaction (pH) is consistently slightly acid (6.1–6.5), and has no significant variation with altitude.

The B horizon, though locally not developed, tends to be 4 to 8 inches thick (table 7, p. 39). It is commonly brown (10*YR* 5/3–5/4), owing to slight oxide coatings of rock fragments and grains. The material is either structureless or has a weak, fine to medium, subangular to angular blocky structure. No clay accumulation is discernible by spindling in the hand. The reaction (pH) of the horizon tends to be medium acid (about 6.0) in the upper part of the altitude range of the facies and slightly acid (about 6.5) in the lower part.

BROWN FOREST FACIES

The Brown Forest facies has only been found along Pack Creek on alluvial sand and silt between altitudes of about 7,800 and 7,000 feet. A profile at the type locality is given in section 25.

The Brown Forest facies varies little. The A horizon is 6 to 18 inches thick and is gray (10*YR* 5/1) to very dark gray (10*YR* 3/1). In places it contains little organic matter. It is commonly structureless, or has only a weak, fine subangular blocky structure. The reaction (pH) is slightly acid (6.1–6.5). No clay accumulation was noted. A B horizon of oxide coatings on fragments and grains is only very locally discernible, and where present it is extremely thin and indistinct (table 8, p. 40). Possibly it is masked by overlap of the lower part of the A horizon.

The Cca horizon is 6 to 12 inches thick, and it is very pale brown 10*YR* 7/4) to pale brown (10*YR* 6/3) (table 8). Slight calcium carbonate accumulation is locally visible along root casts, structural openings, or on the undersides of rock fragments. The reaction (pH) is neutral to mildly alkaline (7.0–7.5).

In some places, the soil is represented by 2 or 3 thin, closely spaced azonal soils that merge and separate in such a way as to suggest alternating deposition and soil formation on intermittently aggrading flood-plain channels.

BROWN SOIL FACIES

The brown soil facies occurs between altitudes of about 7,000 and 5,100 feet. It is developed on alluvial gravel of the lower member of the Beaver Basin formation beneath alluvial gravel of the upper member along Pack Creek between Hell Canyon and Brumley Creek and along Placer Creek from an altitude of about 5,600 feet to about 5,100 feet, where it changes to a Sierozem facies. It is also exposed on eolian sand and silt of the lower member of the Beaver Basin formation, overlain by eolian sand and silt of the upper member, along a ditch at the northeast corner of North Mesa (fig. 39). Typical profiles are given in sections 26 and 27.

The A horizon of the Brown soil facies ranges in thickness from 4 to about 18 inches. It is commonly gray (10*YR* 5/1) to dark gray brown (10*YR* 4/2) with a reddish hue (5*YR*) where it is derived from sandstone. The structure ranges from moderate fine columnar to weak subangular or angular blocky, the latter where the mantle contains clay. The reaction ranges from slightly acid to neutral (6.5–7.0), except where secondary calcium carbonate has accumulated.

The B horizon is brown (7.5*YR* 5/4–10*YR* 5/3) or reddish brown (5*YR* 5/4) where it is derived from sandstone (table 9, p. 42). It ranges in thickness from 6 to 8 inches and is structureless, weakly columnar, or weakly blocky. It contains little illuviated clay but is commonly formed on slightly plastic parent mantle. Its reaction (pH) ranges from neutral to mildly alkaline (7.0–7.5).

The Cca horizon ranges in thickness from about 1 foot at higher altitudes to 2 feet at lower altitudes (table 9). It is commonly thicker on coarse-textured deposits and thinner on fine-textured deposits. The color is light brown (7.5*YR* 6/4) to pale brown (10*YR* 6/3), locally light reddish brown (5*YR* 6/4) on mantle derived from sandstone. Calcium carbonate forms thin films on both rock fragments and matrix. The horizon tends to be structureless, and it has a mild moderately alkaline reaction (pH 7.5–8.4).

A poorly drained phase of the Brown soil facies is developed on alluvium of the Beaver Basin formation in many of the lower valleys. It has a dark A horizon as much as 3 feet thick, no B horizon, and nodular gypsum and rusty streaks in the Cca horizon.

SIEROZEM FACIES

The Sierozem facies of the Pack Creek soil is developed in Castle Valley from an altitude of about 5,100 to about 4,600 feet and in Spanish Valley from an altitude of about 4,600 feet to about 4,000 feet at the Colorado River. Typical profiles are given in sections 28 and 40. Its position is further illustrated in figure 42.

The A horizon is thin, and in places it is barely discernible. It tends to be gray brown (10*YR* 5/2), but on sandy mantle it has a more reddish hue (5*YR*). The structure is commonly weak and blocky, and the material is nonplastic. The reaction (pH) is moderately alkaline (about 8.0). Slight accumulations of calcium carbonate are present throughout.

The Cca horizon is about 2 feet thick, and it is pale brown (10*YR* 6/3) to light reddish brown (5 *YR* 6/4) (table 10, p. 43). Calcium carbonate forms thin films on rock fragments and grains. The horizon is structureless, nonplastic, and has a moderately alkaline reaction (pH 8.0–8.5).

A poorly drained phase of the Sierozem facies is seen in several places along Pack Creek between City Park and the crossing of U.S. Highway 160 in Spanish Valley, in Castle Valley along Placer Creek above Castle Creek, and on the south flank of the mountains along West Coyote Creek.

The poorly drained phase has a dark gray (2.5*YR* 4/1) A horizon 1 to 5 feet thick, and it is weakly calcareous throughout. Carbonate accumulations extend as a Cca horizon for 12 to 24 inches below the A horizon. Blebs, nodules, or stringers of powdery gypsum are common, and in places they impart a greenish hue. The deposits on which the profile is developed tend to contain more silt and clay than the normally sandy alluvium.

These characteristics suggest that parts of the flood plains were swampy, supported an appreciable amount of vegetation, and received occasional increments of silt and clay while the Pack Creek soil was forming.

SUMMARY OF CHARACTERISTICS OF THE PACK CREEK SOIL

The Pack Creek soil displays certain characteristics that set it apart from others, regardless of its facies or of the parental mantle. About 40 exposures on well-drained, relatively gentle slopes support the following generalizations:

1. The soil was observed only where it is buried beneath deposits bearing the Castle Creek soil, and, in many places, on deposits overlying the Lackey Creek soil.
2. The upper limit of each of the four facies represented is lower than for similar facies of the Spring Draw, Lackey Creek, or Castle Creek soils (fig. 19). The pedalfer-pedocal boundary (altitude 7,800 feet) is higher than that of the Spanish Valley soil.
3. The B horizon is only locally developed in the Brown Podzolic and Brown soil facies. Its range in thickness, 4 to 8 inches, is thinner than in any except the Spanish Valley soil.
4. The hue of the B horizon is consistently 10*YR* except where it is developed on reddish sandy mantle, where it is 7.5*YR* or 5*YR*.
5. The chroma of the B horizon is consistently 3 to 4; the value is rather consistently 5.
6. The structure of the B horizon is weak or lacking. Where present, it is commonly subangular to angular blocky, very locally columnar on fine-textured parent mantle.
7. The plasticity of the B horizon is similar to that of the parent mantle and reflects no discernible clay accumulation.
8. The reaction (pH) of the B horizon ranges from 6.0 at about 9,500 feet to 7.0 at about 7,000 feet, below which it ranges to mildly alkaline (about 7.5).
9. The Cca horizon ranges in maximum thickness from about 1 foot to about 2 feet at all altitudes. It is commonly thickest on coarse deposits and thinnest on fine deposits.
10. The reaction (pH) of the Cca horizon ranges from neutral (about 7.0) at 7,800 feet to moderately alkaline (8.0–8.5) below 5,100 feet.
11. Although no quantitative measurements have been made, the Cca horizon at any given altitude seems to contain less calcium carbonate than any other soil except the Spanish Valley soil.
12. The Pack Creek soil, though now well drained, appears to have formed in many places on poorly drained alluvium. Poorly drained Brown soil and Sierozem facies are the most widespread; all other facies appear to have formed mostly under well-drained conditions.

EROSION SURFACE BETWEEN THE UPPER AND LOWER MEMBERS OF THE BEAVER BASIN FORMATION

Stream erosion between deposition of the members of the Beaver Basin formation was relatively slight and localized. Apparently no arroyo-cutting preceded development of the Pack Creek soil. Instead, stream deposits appear to have changed gradually from coarse, through fine, to wet-bottom flood-plain silts in which the Pack Creek soil developed with only occasional increments.

Later, streams eroded their flood plains where they emerge from canyons to enter broad, flat-floored valleys. The maximum erosion, about 20 feet, was along Pack Creek just upstream from Spanish Valley (pl. 5). Less erosion took place at the mouth of Mill Creek Canyon and in upper Castle Valley. In other places, the Pack Creek soil was buried by alluvium of the upper member of the Beaver Basin formation without significant intervening erosion.

CASTLE CREEK SOIL

DEFINITION AND TYPE LOCALITY

The Castle Creek soil is a distinctive moderately developed zonal soil formed on the upper member of the Beaver Basin formation, on the lower member where it is not overlain by the upper, and locally on older deposits exposed at that time. In a few places, it was seen superposed on the Spring Draw and Lackey Creek soils, which, however, it does not mask. It was not observed on bedrock.

The type locality is at the confluence of Castle Creek and Placer Creek in Castle Valley (NW¼SW¼ sec. 8, T. 25 S., R. 23 E.) (fig. 42). Here the soil is developed on alluvial sand and silt of the upper member of the Beaver Basin formation, which overlies the Pack Creek soil and is overlain by the lower member of the Gold Basin formation. Details are given in section 40.

The Castle Creek soil is formed on till of both members of the Beaver Basin formation throughout the mountains, and it can be traced thence onto deposits correlated with the Beaver Basin formation. Some of these relations are sketched in figure 30. The soil is

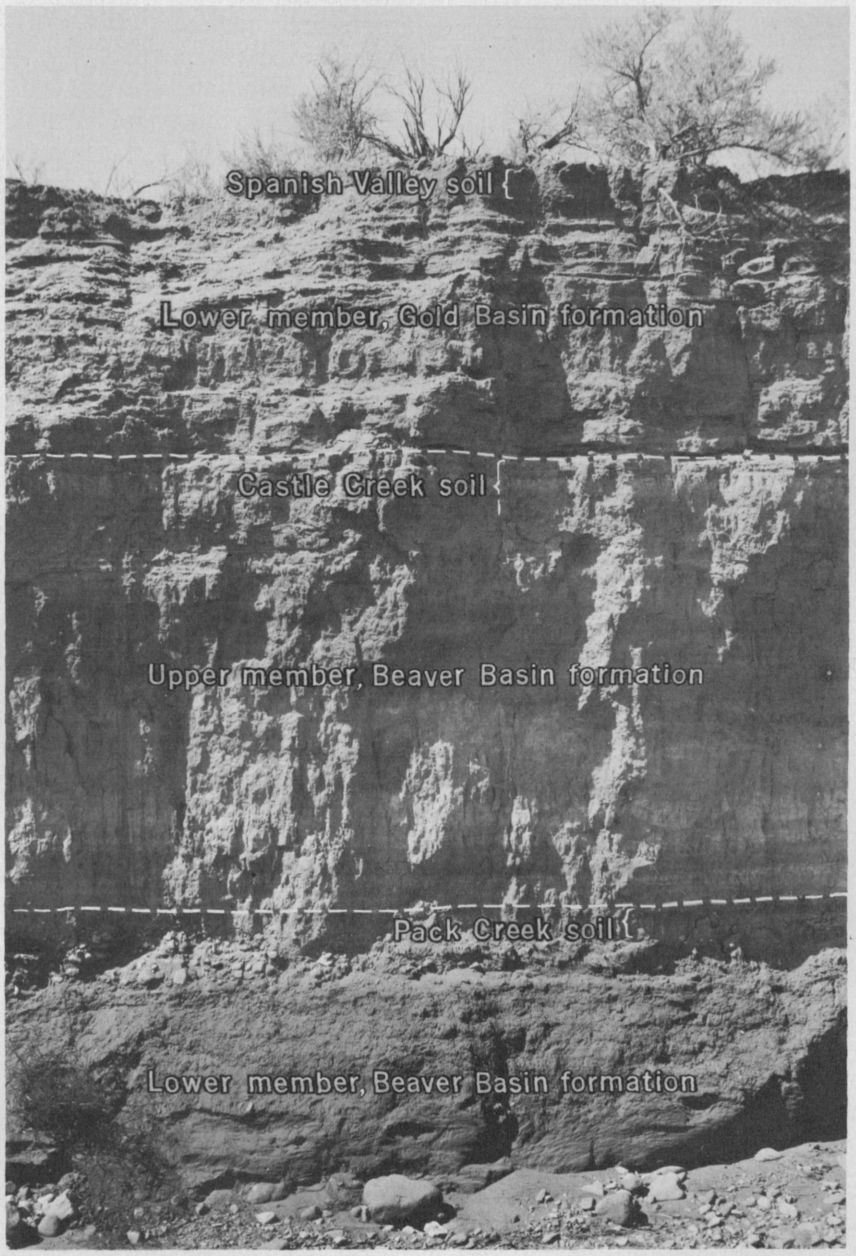


FIGURE 42.—Type locality of the moderately developed Castle Creek soil at the confluence of Castle Creek and Placer Creek in Spanish Valley. Here the Sierozem facies of the soil is developed on alluvial sand and silt of the upper member of the Beaver Basin formation, and is overlain disconformably by alluvial sand and silt of the lower member of the Gold Basin formation on which the very weakly developed Spanish Valley soil is formed. The weakly developed Pack Creek soil is locally preserved beneath the disconformity separating the upper member of the Beaver Basin formation from the lower member in the lower part of the photograph.

preserved in several places where the Beaver Basin formation, on which it is developed, overlies the Lackey Creek soil (figs. 28, 43).

The relations of the Castle Creek soil are well demonstrated along Pack Creek, where the soil is developed on alluvial gravel of the upper member of the Beaver Basin formation, and it can be traced from a moraine in the northwest cirque of South Mountain downstream to the Colorado River. Along much of this distance, the soil is overlain by the lower member of the Gold Basin formation bearing the Spanish Valley soil.

The Castle Creek soil is also developed on alluvial gravel of the lower member of the Beaver Basin formation where that gravel forms a terrace distinct from that of the upper member. However, where the two members form a compound fill the Pack Creek soil is weakly developed between them. These relations

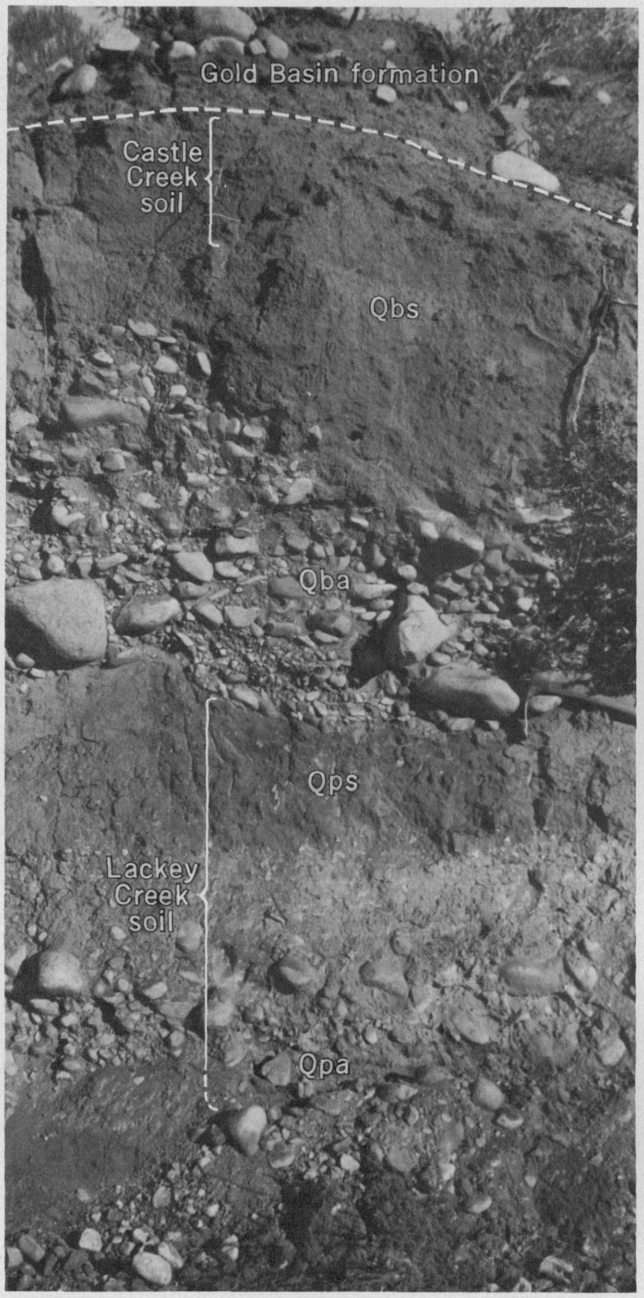


FIGURE 43.—Exposure in the wall of Castle Creek in Castle Valley showing a Brown soil facies of the Castle Creek soil developed on alluvial deposits of the Beaver Basin formation (*Qbs* and *Qba*) which overlie a Brown soil facies of the Lackey Creek soil on alluvial deposits of the Placer Creek formation (*Qps* and *Qpa*).

clearly indicate that the Castle Creek soil does not occur at two stratigraphic horizons. It is present on the lower member, where that member is not buried by the upper member, because its profile is stronger and has masked the Pack Creek soil.

FACIES OF THE CASTLE CREEK SOIL

The Castle Creek soil is developed in four distinct facies, each with a particular range in latitude, and grades into adjoining facies through about 200-foot changes in elevation (pl. 2, fig. 19). A Brown Podzolic facies occurs above about 8,000 feet; a Brown Forest facies, between 8,000 and 7,200 feet; a Brown soil facies, between 7,200 and 5,400 feet; and a Sierozem facies, below 5,400 feet (fig. 44). Each facies is weaker than similar facies of the Spring Draw or Lackey Creek soils but is stronger than the Porcupine Ranch, Pack Creek, or Spanish Valley soils.

BROWN PODZOLIC FACIES

The Brown Podzolic facies of the Castle Creek soil occurs above about 8,000 feet as high as 11,500 feet. Profiles developed on till, alluvial gravel, alluvial-fan gravel, talus, and solifluction deposits are generally similar except as they are influenced by the lithologic character of the matrix of the parent material. On frost rubble, the soil is developed either at the base of the rubble (fig. 30 *E*, *F*) or on fines in the interstices of the rubble at depths as great as several feet below its surface (figs. 30*G*, 34). On eolian deposits, the profile is somewhat thinner than it is on coarse-textured deposits, and the B horizon is more prominent. Typical profiles are given in stratigraphic sections 29 through 35.

The A horizon of relict profiles of the Brown Podzolic facies is less than 6 inches thick, and it is probably a product of modern environment. For example, an A_2 subhorizon was observed only beneath a modern spruce forest. The A horizon of buried profiles is 12 to 18 inches thick, very dark gray (10*YR* 3/1), and has a fine granular structure.

The B horizon ranges in maximum thickness from 22 inches at the mountain tops to about 10 inches at 8,100 feet, the lower limit of the facies (table 7, p. 39), but varies considerably at any given altitude. It is locally divisible into an upper, darker B_2 subhorizon and a lower, lighter B_3 subhorizon. The color of the B_2 subhorizon is brown to yellowish brown (7.5*YR*–10*YR* 5/4–5/2). Profiles developed on reddish sandy mantle tend to be 7.5*YR* in hue. In general, however, the B horizon is less red than it is in the Brown Podzolic facies of the Spring Draw or Lackey Creek soils. The material is commonly structureless or has a weak fine crumb or fine subangular blocky structure. It is nonplastic to slightly plastic, and clay accumulation is barely discernible. The reaction (pH) of the horizon ranges from strongly acid (5.1–5.5) in the upper part of the altitude range of the facies to slightly acid or neutral (6.5–6.7) at the lower limit.

In a few places, notably near certain igneous bodies, calcium carbonate has accumulated in the Castle Creek soil on the Beaver Basin formation at altitudes well within the range of the Brown Podzolic facies. Typical is the profile described in section 36.

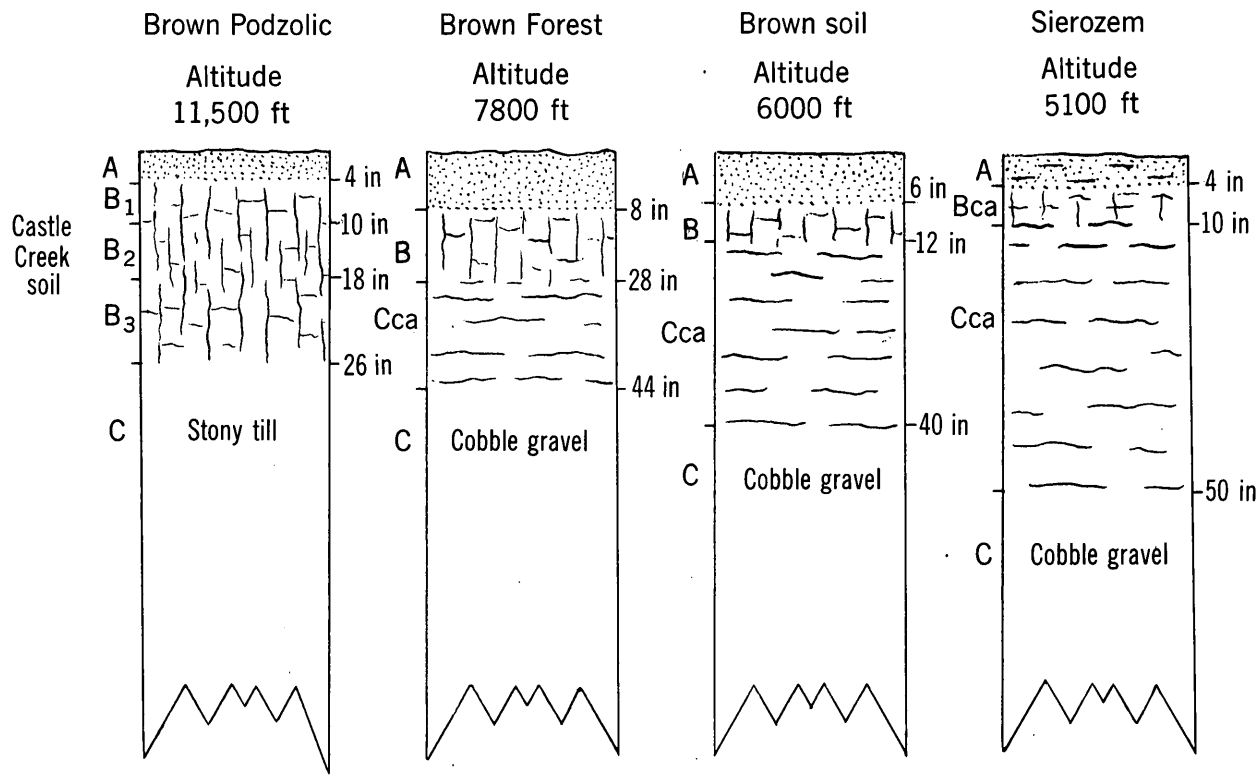


FIGURE 44.—Typical diagrammatic profiles of the four major facies of the Castle Creek soil, showing their general character and thickness.

The carbonate in these profiles probably came from secondary calcite in the bedrock which, after being leached from broken fragments in the mantle was precipitated by subsurface evaporation in the voids. (See section 36.) Although some carbonate is probably introduced with the eolian mantle, the carbonate in the profile seems to be restricted to areas where calcite can be found in the bedrock.

BROWN FOREST FACIES

The Brown Forest facies of the Castle Creek soil occurs in an altitude range between 8,000 and 7,200 feet. It was observed on dioritic alluvial and fan gravel and on quartzose alluvial and eolian sand and silt. Typical profiles are given in sections 25 and 37.

The A horizon of relict profiles is thin and appears to be related to the modern environment. In buried profiles the A horizon is 12 to 18 inches thick, very dark gray (10*YR* 3/1), and has a weak, fine granular or blocky structure.

The B horizon has a maximum thickness of about 10 inches but ranges upward from 4 inches (table 8 p. 40). It is light brown to brown (7.5*YR* 6/4–5/4) and has a fine granular to blocky structure, except on very stony deposits where it is structureless. The material is commonly nonplastic and clay accumulation is not obvious. The reaction (pH) is slightly acid to neutral (6.5–7.3).

The Cca horizon ranges from about 1 to 2 feet in thickness (table 8) and is brown (10*YR* 5/3) to light brown (7.5*YR* 6/3–6/4) or pale brown (10*YR* 6/3). Calcium carbonate forms very thin dendritic films on both rock fragments and matrix. The material is commonly structureless and has a mildly alkaline reaction (pH—about 7.5).

BROWN SOIL FACIES

The Brown soil facies of the Castle Creek soil occurs at altitudes ranging from 7,200 to 5,400 feet. It was observed on dioritic alluvial gravel, on alluvial-fan gravel composed mainly of sandstone, and on quartzose alluvial or eolian sand and silt. Typical profiles are described in sections 22, 27, and 38.

The A horizon of relict profiles is as much as about 1 foot thick, though most are less than 6 inches thick. In buried profiles, the A horizon is commonly about 1 foot thick, dark gray (10*YR* 4/1) and has a weak blocky structure.

The B horizon is 6 to 12 inches thick (table 9, p. 42), brown (7.5*YR*–10*YR* 5/4–5/3), and commonly has a weak fine blocky structure. On some eolian deposits, however, the hue is 5*YR* and the structure is weak fine columnar. The material tends to be nonplastic and has little or no clay accumulation. The reaction (pH) ranges from neutral (about 7.0) at the upper limit of the facies to mildly alkaline (about 7.8) at the lower limit.

The Cca horizon, including locally a Bca horizon, is between 24 and 36 inches thick (table 9) and is commonly light brown to pale brown (7.5*YR*– 10*YR* 6/3). Where developed on reddish sandy mantle, the hue tends to be 7.5*YR* or locally 5*YR*. Calcium carbonate forms thin coatings or films on rock fragments or, in fine-grained mantle, along root casts and structural openings. The horizon is generally structureless, but on fine-grained mantle it locally has a weak to strong, fine, blocky to columnar structure. Its reaction (pH) is moderately alkaline (8.0–8.5).

SIEROZEM FACIES

The Sierozem facies of the Castle Creek soil occurs below an altitude of about 5,400 feet in Castle Valley, in Spanish Valley, and along the Colorado River on alluvial gravel, alluvial-fan gravel, alluvial sand and silt, and eolian sand and silt. Typical profiles are described in sections 28, 39, 40, and 41.

The A horizon of buried profiles is 4 to 10 inches thick. It is reddish gray (5*YR* 5/2) to brown (7.5*YR* 5/2), being reddish when developed on reddish sandy parent mantle. Relict profiles tend to be structureless; buried profiles have a weak to moderate thin platy or fine blocky structure. The reaction (pH) is moderately to strongly alkaline (8.0–8.5).

A B horizon is lacking or present only as a Bca subhorizon about 6 inches thick (table 10, p. 43). It tends to be reddish brown (5*YR* 5/4) because it is generally developed on reddish sandy parent mantle. The horizon is structureless to weakly platy, has no discernible clay accumulation, and has a moderately to strongly alkaline reaction (pH 8.0 – 8.5).

The Cca horizon is 3 to 4 feet thick (table 10) and light reddish brown (7.5*YR* 6/3 – 6/4) to pink (5*YR* – 7.5*YR* 7/4). The horizon lacks soil structure and has a moderately to strongly alkaline reaction (pH 8.5 – 9.0).

SUMMARY OF GENERAL CHARACTERISTICS OF THE CASTLE CREEK SOIL

As a unit embracing four facies under a variety of conditions of vegetation and lithologic properties of parent mantle, the Castle Creek soil has certain characteristics that set it apart from all others in the area.

1. The upper altitude limit of each of the four facies of the Castle Creek soil is lower than for similar facies of the Spring Draw or Lackey Creek soils but higher than for similar facies of all others (fig. 19).
2. The B horizon ranges in maximum thickness from 4 inches at an altitude of 4,200 feet to about 30 inches at 11,000 feet. At any given altitude it thus tends to be thinner than that of the Spring Draw and Lackey Creek soils (fig. 56) but thicker than those of all others.
3. The hue of the B horizon ranges from 5*YR* to 10*YR*. In general, a hue of 7.5*YR* to 10*YR* is more common than in the B horizon of the Spring Draw and Lackey Creek soils (fig. 57*A*).
4. The chroma ranges from 2 to 5 but is more commonly 4 to 5 than in the B horizon of the Spring Draw or Lackey Creek soils (fig. 57*B*). A chroma of 6 was not observed. The range in color value is similar to that of other soils (fig. 57*C*).
5. The structure of the B horizon ranges from columnar to crumb but is more commonly granular to crumb than in the Spring Draw or Lackey Creek soils (fig. 58*A*). The structure is also more commonly fine to very fine, and it is weaker than in the Spring Draw and Lackey Creek soils (fig. 58 *B*, *C*).
6. The material of the B horizon ranges from plastic to non-plastic (fig. 59). However, the plasticity is so similar to that of the parent mantle that illuviated clay is rarely distinguishable, and it is clearly much less than in the Spring Draw or Lackey Creek soils.
7. The reaction (pH) of the B horizon, excluding any Bca subhorizon, ranges from about 7.0 at about 7,200 feet to about 5.0 at an altitude of 12,000 feet (fig. 60). Throughout this range, the pH of the B horizon at any given altitude is, on the average, higher than the pH in the Spring Draw or Lackey Creek soils but lower than in the Spanish Valley soil.
8. The Cca horizon of the Castle Creek soil ranges in maximum thickness from about 8 inches at 8,000 feet, its upper limit, to 44 inches at 4,200 feet (fig. 61). It averages consistently less than the Spring Draw and Lackey Creek soils and more than the Spanish Valley soil.
9. The reaction (pH) of the Cca horizon ranges from about 7.5 at 8,000 feet to 9.0 at 4,000 feet (fig. 60). At any given altitude above about 4,500 feet, the pH tends to be less than that of the Cca horizon of the Spring Draw and Lackey Creek soils.
10. Although no quantitative measurements have been made, the Cca horizon seems to contain less accumulated calcium carbonate than those of the Spring Draw or Lackey Creek soils.
11. Within the mountains, the Castle Creek soil appears to have developed under well-drained conditions. A poorly drained phase is restricted to depressions in till in the Brown Podzolic facies and to local areas on alluvium in the Brown soil and Sierozem facies.
12. The Castle Creek soil appears to have formed while slopes were relatively stable, for profiles on steep slopes are essentially the same as those on gentle slopes. The only observable difference is that the A horizon has been somewhat stripped on steep slopes and thickened at their bases.

EROSION SURFACE BETWEEN THE BEAVER BASIN FORMATION AND GOLD BASIN FORMATION

Stream erosion intervening between the Beaver Basin and Gold Basin formations was considerably less than that following the Placer Creek formation. Development of the Castle Creek soil on steep slopes, cut into the upper member of the Beaver Basin formation, and overlain by the Gold Basin formation, indicates that some cutting, probably shallow arroyos, preceded development of the Castle Creek soil. After the soil developed, the arroyos were deepened to as much as 30 feet and broadened into channels 30 to 300 feet wide. The irregularity of this cutting is demonstrated by the relation of terraces to compound alluvial fills along Pack Creek, as shown in plate 5.

GOLD BASIN FORMATION

DEFINITION

The unit here named the Gold Basin formation includes interfingering or intergradational deposits that overlie the Beaver Basin formation or an erosion surface truncating it. It also locally overlaps the Placer Creek and Harpole Mesa formations.

The Gold Basin formation consists of two members. The lower member, whether buried by the upper member or not, has a very weakly developed azonal soil, the Spanish Valley soil, on it. The upper member has no soil or only a little humus. In places, the upper member is being deposited or reworked intermittently at present. Elsewhere it is an inactive deposit.

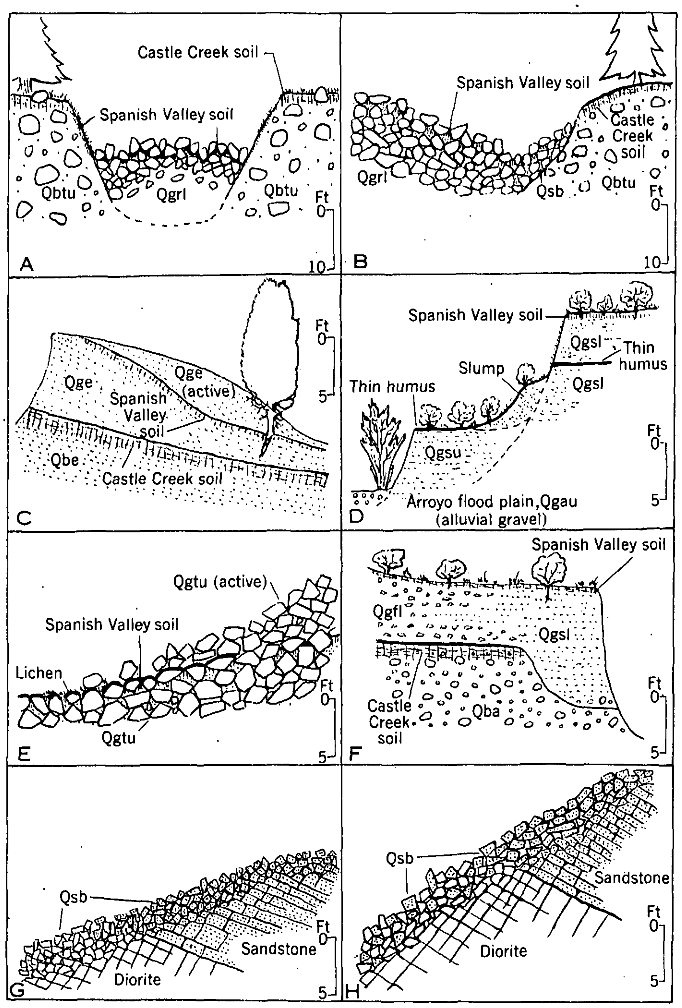
The Gold Basin formation comprises 10 facies: till, rock glaciers, alluvial gravel, alluvial sand and silt, alluvial-fan gravel, slope-wash mantle, talus, solifluction mantle, frost rubble, and eolian sand and silt (fig. 9). Sketches of observed relations of these facies are shown in figure 45. The 2 members of the formation can be distinguished locally in 7 of the facies, and in 4 they are sufficiently widespread to be mapped (pl. 1).

As all facies are nowhere represented in a single section, a type area will be defined on the basis of the rock glaciers, which are more widespread than the till and with which all other facies of the formation can be correlated.

TYPE AREA

The Gold Basin formation is named from a type area in Gold Basin in the Middle Mountain group. Each of the 2 north-facing cirques of Gold Basin contain 2 rock glaciers, 1 nested within and upslope from the other at altitudes of 10,600 and 10,800 feet respectively (fig. 46). The rock glaciers lie upstream from moraines of the Beaver Basin formation and locally breach lateral moraines of both members of that formation.

The outer rock glacier is the lower member of the Gold Basin formation. It has a very weakly developed azonal soil, the Spanish Valley soil, developed on local interstitial fine material, and it supports some grass and scrub spruce. Surface blocks are lichen covered.



A. Sketch of a rock glacier of the lower member of the Gold Basin formation (*Qgrl*), on which the Spanish Valley soil is developed, in a draw cut in till of the upper member of the Beaver Basin formation (*Qbtu*), on which the Castle Creek soil is developed Location: southeast cirque of Beaver Basin.

B. Sketch of a rock glacier of the lower member of the Gold Basin formation (*Qgrl*) on which the Spanish Valley soil is developed, merging with frost rubble of the upper member of the Gold Basin formation (*Qsb*). The rubble is formed from till of the upper member of the Beaver Basin formation (*Qbtu*) and truncates the Castle Creek soil developed on that till. Location: northeast cirque of South Mountain.

C. Sketch of an eolian deposit of Beaver Basin formation (*Qbe*), on which the Castle Creek soil is developed, overlain by an inactive dune of the lower member of the Gold Basin formation (*Qge*), on which the Spanish Valley soil is developed. This dune is being eroded to form an active dune of the upper member of the Gold Basin formation (*Qge*). Location: observed in many places along road east from Moab across the plateau.

D. Sketch of a section of alluvial sand and silt of the lower member of the Gold Basin (*Qgsl*) containing a thin persistent humus zone. The Spanish Valley soil at the surface of the deposit is truncated by the arroyo which contains a shallow fill of alluvial sand and silt of the upper member of the formation (*Qgsu*), on which only a faint humus is formed. This, in turn, is trenched by the present flood plain. Location: the wall of Pack Creek in Spanish Valley just below Summerville Ranch.

E. Sketch of active talus of the upper member of Gold Basin formation (*Qgtu*) overlapping inactive, lichen-covered talus of the lower member of the formation (*Qgtu*) on which the Spanish Valley soil is developed. Location: east cirque of Mount Peale.

F. Sketch of alluvial sand and silt of the lower member of the Gold Basin formation (*Qgsl*) filling and overlapping an arroyo cut in gravel of the Beaver Basin formation (*Qba*) on which the Castle Creek soil is developed. The Spanish Valley soil is developed both on the sand and silt and on alluvial gravel of the lower member of the Gold Basin formation (*Qgfl*) with which the sand and silt interfingers. Location: the wall of a draw tributary to Pack Creek from the south near the confluence of Brumley Creek.

G. Sketch of an active frost-riven rubble sheet of the upper member of the Gold Basin formation (*Qsb*) on the south side of the summit of Mount Peale. In this variety of rubble sheet, blocks riven from subjacent bedrock remain in an essentially residual position, without significant downslope displacement.

H. Sketch of active frost-creep rubble sheet of the upper member of the Gold Basin formation (*Qsb*) on the east slope of Mount Tukuhnikivatz. In this variety of rubble sheet, blocks riven from subjacent bedrock slide or roll downslope for considerable distances.

FIGURE 45.—Some stratigraphic relations of deposits of the Gold Basin formation.

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FIGURE 46.—Type locality of the Gold Basin formation in Gold Basin on the west side of the Middle Mountain group. Paired rock glaciers of the lower (*Qgrl*) and upper (*Qgru*) members of the formation lie in the cirques on the north side of Mount Tukuhnikivatz, up-valley from moraines of the upper (*Qbtu*) and lower (*Qbtl*) members of the Beaver Basin formation on which rubble streams (*Qbb*) are locally developed. A small moraine (*Qgtl*) of the lower member of the Gold Basin formation lies in the cirque to the left of the rock glaciers.

The inner rock glacier represents the upper member of the formation. It is bounded by a well-developed marginal ridge, outside of which is a distinct drainage channel. The deposit bears no soil and supports no vegetation. Blocks at its surface are fresh and unstable. The rock glacier grades headward into active talus and appears to have been active very recently. Permanent snowbanks lie at the head in the shelter of the cirque wall.

FACIES OF THE GOLD BASIN FORMATION

TILL

Small end moraines occur in 11 cirques at altitudes between 10,000 and 11,600 feet. Four cirques are in the Middle Mountain group and 7 are in the North Mountain group. In 9, only a moraine of the lower member is present; in 1, moraines of both members are present; and in 1, a moraine of the lower member lies below a rock glacier of the upper member. The average altitude of a total of 33 moraines and rock glaciers of the lower member is 11,100 feet, that of one moraine and 8 rock glaciers of the upper member is 10,130 feet.

All moraines lie upstream from those of the Beaver Basin formation, and outwash from them overlaps or lies in gullies that cut the Castle Creek soil on the Beaver Basin formation. The moraines bear the Spanish Valley soil and support an extensive tundra vegetation and scrub spruce.

The lone moraine of the upper member, at the head of the North Fork of La Sal Creek, lies upstream from a moraine of the lower member, and an outwash channel from it crosses the lower moraine. It has no soil and supports only a very sparse pioneer vegetation.

The moraines are 15 to 20 feet high, about the same size as many small moraines of the Beaver Basin formation, but they appear fresher and have more bouldery slopes (fig. 47). The till consists mostly of coarse angular rock detritus and some sandy interstitial material. The material is mostly of fresh diorite except where it is derived from hydrothermally altered rock.

FIGURE 47.—A rocky end moraine of the lower member of the Gold Basin formation overlapping a moraine of the upper member of the Beaver Basin formation in the north cirque of Beaver Basin. A small rock glacier of the upper member of the Gold Basin formation lies to the right of the snowbank in the cirque head.

Outwash channels that were cut while the moraines were formed are well preserved, but little later dissection is evident. Some outwash channels consist of narrow shallow trenches floored with boulders lacking interstitial matter, and they have local enclosed depressions along them. The boulders tend to lie parallel to the trench and with their slabby sides at a high angle. This and the enclosed depressions suggest that the trenches result from gradual settling of the boulders as subsurface drainage washed interstitial material from between them.

ROCK GLACIERS

Rock glaciers occur in 23 cirques. Seven cirques contain rock glaciers of both members; 1, a rock glacier upslope from a moraine of the lower member; and 15 contain only a rock glacier of the lower member. Rock glaciers of this formation truncate, overlap, or lie upstream from rock glaciers or moraines of the Beaver Basin formation (figs. 32, 46). Those of the lower member that contain interstitial fine material at their surfaces have the Spanish Valley soil developed on them, and support scrub spruce or tundra vegetation. Blocks on their surfaces are lichen covered. The deposits grade headward into inactive talus on which the Spanish Valley soil is also developed, and they are overlapped by active talus. Rock glaciers of the upper member bear no soil and support no vegetation (fig. 48). They grade into active talus at the cirque headwall but themselves display no evidence of present activity.

FIGURE 48.—A rock glacier of the upper member of the Gold Basin formation overlapping a lateral moraine of the lower member in a cirque on the south side of Miners Basin.

The rock glaciers of the Gold Basin formation appear much fresher than those of the Beaver Basin formation. They are lobate, have steep snouts, and in places are as much as 70 feet high.

The deposits range from 100 yards to half a mile in length and from 100 to 600 yards in width. Their surface gradients range from 2° to 15°. Surface features are similar to, but more pronounced than, those of rock glaciers of the Beaver Basin formation. For example, a rock glacier of the lower member in the northeast cirque of South Mountain has a kettlelike depression in its terminal zone that is 100 feet across, 30 feet deep, and contains water throughout the summer. It also has steep-sided crevasselike furrows, 30 to 40 feet long, 10 to 15 feet wide, and 6 to 10 feet deep, along its northern side.

The deposits appear to consist mostly of unsorted, angular, blocky rubble, in which individual fragments average about 2 feet in diameter but are as much as 10 feet. However, exposures of till-like material along their flanks and the presence of water in kettlelike depressions suggest that the blocky rubble irregularly mantles a relatively impermeable core. The rubble may be as much as 30 feet thick in places.

ALLUVIAL GRAVEL

Alluvial gravel of the Gold Basin formation is mostly confined to the major flood plains and to low, narrow terraces along them. The only canyon containing extensive gravel is that of Pack Creek, where the gravel either overlaps the Castle Creek soil (fig. 49) or lies on an erosion surface that dissects alluvium of the Beaver Basin formation. Locally, deposits of gravel form a compound fill in which gravel of the lower member overlies alluvium of the Beaver Basin formation and is overlain by gravel of the upper member, with both the Spanish Valley and Castle Creek soils in their appropriate places. More commonly, however, gravel of the lower member bearing the Spanish Valley soil underlies a terrace, 10 to 15 feet above the stream. The terrace is cut below the Beaver Basin formation and is itself trenched by lower gravel that has no soil. These relations along Pack Creek are shown on plate 5. In the mountains, a few small outwash gravel deposits, bearing the Spanish Valley soil, grade headward into moraines of the lower member. The gravels have numerous bars and channels and consist of poorly sorted, crudely bedded, subangular to subrounded gravel that contains local lenses of sand and silt. The lower member is as much as 20 feet thick; the upper member is commonly less than 10 feet thick. Except for small outwash deposits, most of the gravel is locally derived from older alluvial or solifluction deposits.

ALLUVIAL SAND AND SILT

Alluvial sand and silt of the Gold Basin formation is widely distributed in the lower valleys west of the mountains. Its relations to alluvium of the Beaver Basin are like those of the alluvial gravel facies, with which it interchanges several times along certain valleys,

FIGURE 49.—Alluvial gravel of the lower member of the Gold Basin formation (*Qgal*), on which the Spanish Valley soil is developed, overlapping the Castle Creek soil on alluvial gravel (*Qba*) of the Beaver Basin formation. Exposure is along the upper sector of Pack Creek at an altitude of 9,100 feet.

FIGURE 50.—Alluvial sand and silt of the lower member of the Gold Basin formation (*Qgsl*), on which the Spanish Valley soil is developed, filling a trench cut in alluvial gravel of the Beaver Basin formation (*Qba*) on which the Castle Creek soil is developed. Exposure is along Pack Creek below its confluence with Dorry Creek.

except that it fills many arroyos cut in the Beaver Basin formation and overlaps the Castle Creek soil. Like the gravel, it forms a compound fill in some places (fig. 52), and elsewhere it forms a pair of terrace deposits.

These conditions are well illustrated along Pack Creek Canyon (pl. 5). In the upper canyon, alluvial gravel of the lower member overlies the Castle Creek soil on gravel of the Beaver Basin formation. Near Hell Canyon, it converges into a trench cut in terraced gravel of this formation. Near Dorry Creek, it changes facies to alluvial sand and silt that nearly fills a trench cut in this alluvial gravel (fig. 50). Farther downstream the facies changes again to gravel, trenched within gravel of the Beaver Basin formation. At the south end of Spanish Valley, the gravel overlaps the Castle Creek soil on gravel of the Beaver Basin formation. In the central valley, the facies changes again to sand and silt, which overlaps first alluvial gravel and then sand and silt of the Beaver Basin formation as far as the Colorado River.

The alluvial sand and silt is mostly light reddish brown to light red, poorly sorted, and well bedded. Locally, near salt plugs in lower Castle Valley, it is bluish gray, owing to its high content of sulphate. In places it is mostly coarse to fine sand; in others, fine sand and silt. Very locally, it contains thin layers of silty clay.

The lower member is as much as 20 feet thick and bears the Spanish Valley soil. It contains a few small gastropods and pelecypods, chiefly in clayey layers and in the uppermost deposits, on which the Spanish Valley soil is developed. Hearth sites containing charcoal were found at the following localities:

1. NW¼NW¼ sec. 22, T. 27 S., R. 23 E. North bank of Pack Creek below confluence of Bromley Creek, 20 yards east of road crossing. Two hearths in lower member overlain by 1 foot of upper member.
2. NW¼NW¼ sec. 22, T. 27 S., R. 23 E. Same as locality 1, but 1,100 yards east of road crossing. Three hearths in 12-foot fill of lower member trenched into gravel of Beaver Basin formation and capped by a few inches of upper member.
3. SE¼NE¼ sec. 22, T. 26 S., R. 22 E. Along short arroyo tributary to Pack Creek three-quarters of a mile northwest of dam in Spanish Valley. Type locality of Spanish Valley soil. Two hearths, flaked chips, and one point found in lower member, which is overlain by 3 to 5 feet of upper member.
4. SW¼NE¼ sec. 1, T. 25 S., R. 22 E. North bank of Castle Creek at lower end of Castle Valley. One hearth in lower member which forms higher of two terraces above the stream. Lower terrace, underlain by upper member, is barren.
5. NW¼NW¼ sec. 1, T. 25 S., R. 22 E. Castle Creek in canyon below Castle Valley, below point where stream leaves alluvial fill and cuts through rock. Two hearths in lower member which forms higher of two terraces along stream. Lower terrace, underlain by upper member, is barren.
6. NW¼NW¼ sec. 1, T. 25 S., R. 22 E. Castle Creek, one-quarter of a mile downstream from locality 5. One hearth 15 feet below top of lower member which forms higher of 2

terraces along stream. Lower terrace, underlain by upper member, is barren.

7. NW¼SW¼ sec. 8, T. 25 S., R. 23 E. South wall of Castle Creek, just above confluence with Placer Creek. Three hearths about 6 feet below top of lower member which is overlain by upper member, here 3 feet thick.

The hearths are 2 to 3 feet in diameter and 2 to 8 inches deep. Some are irregularly lined with flat slabs of sandstone. Artifacts, consisting of flaked chips and one point, were found in them at locality 3. The point was identified by Alice P. Hunt (oral communication, 1952) as being similar to points of "pre-pottery" age found by her at the surface of deposits no younger than the lower member of the Gold Basin formation (Hunt, A. P., 1954). Carbon-isotope analysis of charcoal from this locality by the U.S. Geological Survey laboratory (sample W-143) yielded an age of 2,800± 200 years (Rubin and Suess, 1955, p. 484).

The upper member is generally less than 10 feet thick and bears no soil or only a thin, faint platy humus horizon. It contains a few small pelecypods and gastropods. Fragments of pottery were found in terraces along Pack Creek between Moab and the Colorado River.

ALLUVIAL-FAN GRAVEL

Alluvial-fan gravel of the Gold Basin formation is widely distributed, though individual deposits are small. The deposits are all locally derived. In the mountains, steep cones of coarse and fine angular debris grade headward into talus. Lower down they form gently sloping fans, composed mainly of angular chips of sandstone and shale in a silty matrix that grade headward into slope-wash mantle or talus along major valleys. Coarser, locally bouldery deposits occur where intermittent tributaries join perennial drainage.

In general, the deposits head in gullies cut in the Beaver Basin formation, which they overlap downstream. Many grade downslope into alluvial gravel or sand and silt of either member of the Gold Basin formation.

The fan gravel is crudely bedded and poorly sorted. Some structureless layers probably represent mudflows. Torrent or mudflow channels and levees are common on seasonally active deposits.

SLOPE-WASH MANTLE

Thin, sporadic deposits of active and inactive slope-wash mantle of the Gold Basin formation overlie or transect deposits of the Beaver Basin and older formations throughout the area, especially in the lower parts. No soil, or only a thin azonal soil, is developed on these deposits. Locally derived, poorly sorted debris with crude discontinuous bedding forms deposits a few inches to as much as 6 feet thick. Some are largely of sand and silt, and others contain angular rock fragments. Most of the deposits have smooth slopes, but the surfaces of some are scored by shallow rills. No attempt was made to map or subdivide these deposits.

TALUS

Most talus of the Gold Basin formation lies in cirques, though a few small, sheetlike deposits or scattered large blocks skirt canyon walls. The deposits overlap the Beaver Basin formation or lie in gullies that dissect it. They grade into till, rock glaciers, or alluvial-fan gravel of the Gold Basin formation. Some are fresh and receive seasonal accretions; others are lichen covered and appear inactive. A few of the deposits, composed largely of fine-grained material, support sparse vegetation and have a very weak azonal soil.

Clear distinction of the two members of the Gold Basin formation in talus deposits is generally impossible. Talus that merges with moraines or rock glaciers of the lower or upper members can of course be correlated, and active deposits are part of the upper member. Inactivity is not in itself a criterion of stratigraphic position, and a soil-profile is rare on coarse deposits. Many are partly active and partly inactive, as though talus development were currently waning.

The upper slopes of the smooth concave talus surfaces range from 24° to 38°. Many are scored by small channels and levees. Most of them consist of coarse, angular rock fragments and finer interstitial debris crudely bedded parallel to the slope. The fine-grained matter is more abundant on the upper slopes of the deposits, and coarse debris is more abundant near the toes.

Most deposits grade downslope into other facies or thin to a featheredge over subjacent material. Some, however, end in protalus lobes or protalus ramparts.

SOLIFLUCTION MANTLE

Active solifluction mantle of the Gold Basin formation occurs below a few snowbanks at high altitudes. The deposits are all small and consist of angular rock framents in an unsorted silty sand matrix. Some have a cover of tundra vegetation; others are barren.

Inactive solifluction mantle of the Gold Basin formation also exists, but thick vegetation prevents differentiation from that of the Beaver Basin formation except by excavation of each individual deposit.

No attempt was made to map these deposits.

FROST RUBBLE

Frost rubble of the Gold Basin formation abounds on summit uplands and slopes as steep as 42° throughout the higher mountains. Its lower limit is at altitudes between 11,000 and 11,400 feet on the west flank of the mountains and between 10,400 and 11,200 feet on the east flank. Some deposits develop from till or

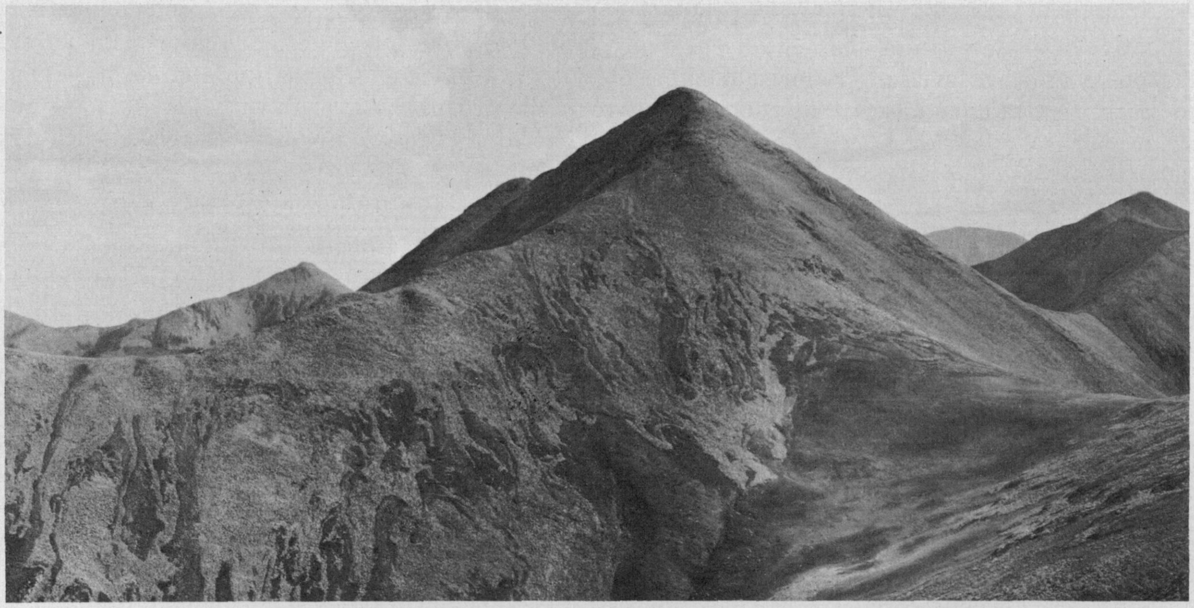

FIGURE 51.—Rubble sheets of the Gold Basin formation merging downslope into rubble rills that are formed from solifluction mantle of the Beaver Basin formation on which the Castle Creek soil is developed. Those on Castle Mountain are formed on diorite bedrock; those on North Peak are formed on sandstone. Most of the deposits are inactive.

solifluction mantle of the Beaver Basin formation and transect the Castle Creek soil on them. Others appear to represent local regenerations of surrounding frost rubble of the Beaver Basin formation. Still others develop on bedrock but overlap the Beaver Basin formation along their lower margins. A few grade into till, rock glaciers, talus, or alluvium of the Gold Basin formation.

The several kinds of rubble are the same as frost rubble of the Beaver Basin formation described on page 62, but the deposits are smaller, fresher and more unstable than those.

Frost creep and frost-riven rubble sheets on bedrock are the most widespread (fig. 51). Frost-sorted rubble sheets on summit uplands are commonly associated with sorted polygons, and those on steep slopes tend to grade laterally into extensive rubble festoons and rubble rills. Most of them are on solifluction mantle of the Beaver Basin formation. Rubble streams are limited to steeply sloping upland swales and are predominantly of frost-sorted origin. Most of them are less than 100 yards long, and none as large as those common in the Beaver Basin formation were seen.

Frost rubble of the Gold Basin formation includes inactive and active deposits, probably related respectively to the lower and upper members. Inactive deposits tend to lie downslope from or to enclose the active deposits. Blocks at their surfaces are sparsely covered with lichen and in places, a very weak soil is formed at bases or on eolian silt within their interstices. Active deposits are very unstable and support no lichen. The ground in the source deposits beneath small block streams was frozen to a depth of about 3 feet in mid-July of 1950. Most of the ice is interstitial, but some of it forms clear layers, 1 to 2 inches thick, with cleavage normal to the surface.

Modern frost creep is locally demonstrated by rubble sheets gradually encroaching on scrub spruce, as on the south slope of Green Mountain, and by terminal ramparts against mature trees near the summit of South Mountain (fig. 52). The growth rings of the scrub spruce are considerably thinner on the upslope side, against which pressure is being applied, than on the downslope side.

FIGURE 52.—An active rubble sheet of the upper member of the Gold Basin formation encroaching against a spruce tree at an altitude of 11,200 feet on the south side of South Mountain.

Although undoubtedly some of the frost rubble has become inactive in modern times. the relations of many inactive deposits to other facies of the lower member of the Gold Basin formation indicate that some of these deposits are part of that member. Active deposits cutting across inactive deposits and constructing terminal ramparts with them suggest rejuvenation associated with the upper member.

EOLIAN SAND AND SILT

Eolian sand or silt of the Gold Basin formation forms scattered dunes and an extensive drift mantle in Spanish Valley and on the plateau east of Moab. A few small dunes also occur along West Coyote Creek and along the Colorado River north of Moab. Some lie conformably on, or are interlayered with, alluvial sand and silt of the Gold Basin formation; others overlie or transect the Castle Creek soil on the Beaver Basin formation. Still others overlie or transect older soils. In the mountains, the deposits form a thin structureless mantle most readily seen in the interstices of talus, frost rubble, or rock glaciers of the Gold Basin formation. They also lie conformably on other facies of the Gold Basin formation or disconformably on older deposits. Some are so thin that they are difficult to distinguish from older eolian deposits.

The dunes and drift mantle of the lower areas consist mostly of light reddish-brown, medium- to fine-grained, crossbedded sand. The deposits are mostly more than 90 percent quartz, but along Spanish Valley they contain as much as 30 percent feldspar and a trace of mafic minerals.

Individual dunes are small elliptical masses that tend to be oriented in a northerly direction. Most are only 3 to 6 feet high, but some that overlap bluffs are as much as 30 feet high. Locally, several dunes join to form an irregularly elongate mass.

The drift mantle forms thin irregular, hummocky sheets, scarred by numerous blowouts. Some of the blowouts are floored by the calcareous horizon of the Castle Creek or Lackey Creek soils; others are floored by bedrock. The deposits are characterized by numerous sets of short variably oriented cross laminae, separated by shallow blowout disconformities.

The structureless mantle of the mountains consists mostly of well-sorted, pale-red to pinkish-gray, fine quartz sand or silt, a few inches to as much as 10 feet deep.

On the plateaus west of the mountains and in Spanish Valley, the deposits comprise two distinct generations. Most are inactive, support vegetation, and bear a very weak soil. Within, and in places enveloping or transgressing, these inactive deposits, however, are small active deposits. The very weak soil on inactive deposits can locally be traced onto alluvium of the lower member of the Gold Basin formation and so most inactive deposits probably correlate with the lower member of the formation; active deposits correlate with the upper member.

SPANISH VALLEY SOIL

DEFINITION AND TYPE LOCALITY

The Spanish Valley soil is that very weakly developed essentially azonal profile of weathering formed on the lower member of the Gold Basin formation. Though not so recognized, it probably also formed on older Quaternary deposits from which preexisting soils had been stripped at that time. It was not observed on bedrock, nor was it seen superposed on older soils. The soil is either overlain conformably by the upper member of the formation or cut by shallow valleys in which the upper member is deposited.

The Spanish Valley soil is named from a type locality in Spanish Valley in the wall of a short arroyo tributary to Pack Creek, about three-quarters of a mile below the dam in SE¼NE¼ sec. 22, T. 26 S., R. 22 E. The Spanish Valley soil is here developed on alluvium of the lower member of the Gold Basin formation that contains charcoal, hearth sites, stone points, and worked flints. It is overlain by interbedded alluvial and eolian deposits of the upper member, which has no soil or only a very faint modern humus. A section measured in the arroyo is given in section 44 and is shown in figure 53.

The stratigraphic relations of the Spanish Valley soil can be observed in many places. In northern Spanish Valley, it is exposed almost continuously on alluvium of the lower member of the Gold Basin formation on a terrace 15 to 20 feet above Pack Creek. In the face of the terrace, the Castle Creek and Pack Creek soils are also exposed. Alluvial gravel of the upper member of the Gold Basin formation forms a lower terrace and the flood plain.

This same successsion was seen along Placer Creek in lower Castle Valley and along Buck Hole Creek in Browns Hole.

In the higher mountains, the Spanish Valley soil occurs on till and rock glaciers of the lower member of the Gold Basin formation. These deposits are transgressed by moraines or rock glaciers of the upper member, which bear no soil, and lie upstream from moraines or rock glaciers of the Beaver Basin formation. In many places, the Spanish Valley soil can be traced laterally onto other facies of the lower member that are overlain or trenched by like facies of the upper member. Relations observed at several localities are sketched in figure 45.

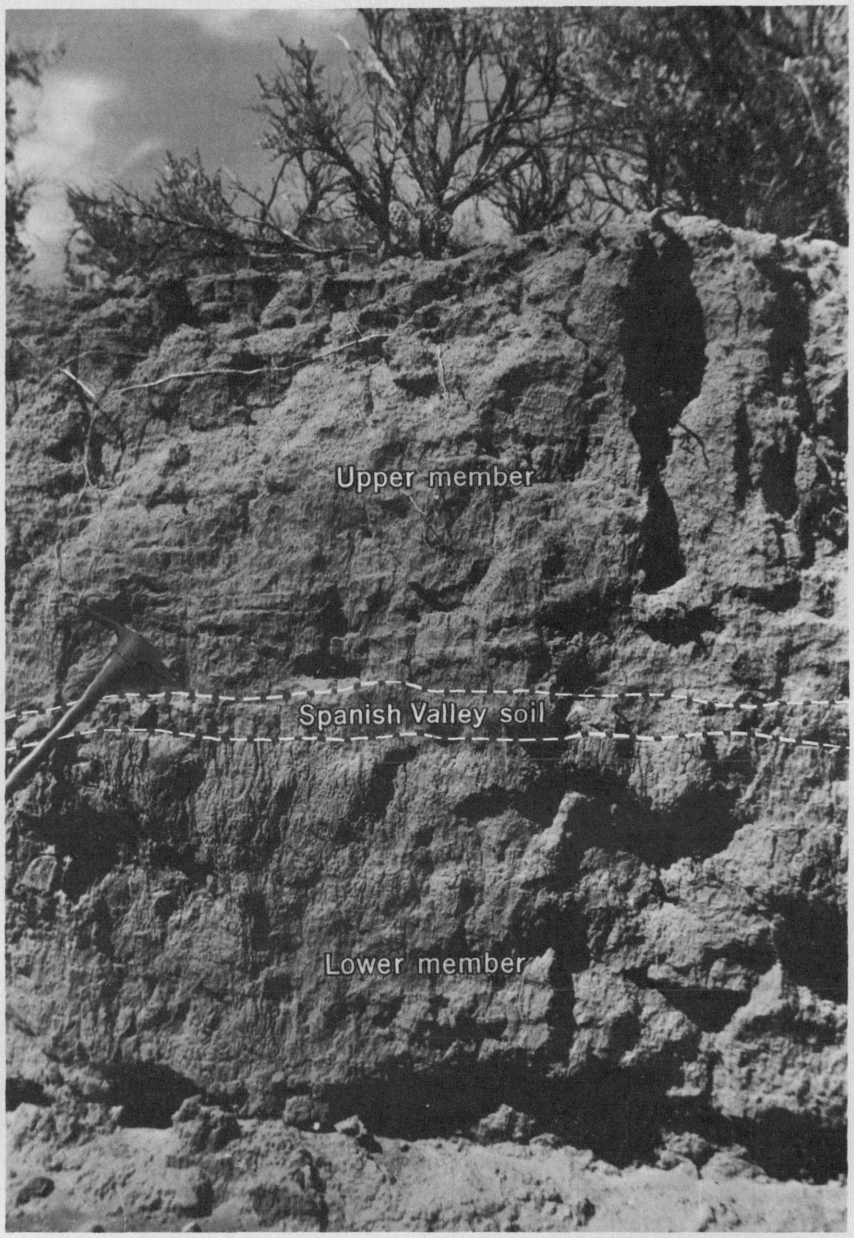

FIGURE 53.—Type locality of the Spanish Valley soil in the wall of an arroyo tributary to Pack Creek at a point about three-quarters of a mile downstream from the dam in the central sector of Spanish Valley. The very weakly developed azonal pedocal facies of the soil is here developed on alluvial sand and silt of the lower member of the Gold Basin formation, containing hearth sites and pre-pottery artifacts, and is overlain by alluvial sand and silt of the upper member of the formation on which no soil or only a very faint humus is formed.

FACIES OF THE SPANISH VALLEY SOIL

The Spanish Valley soil cannot be differentiated into facies equivalent to great soil groups because it is essentially azonal. However, incipient Pedalfer and Pedocal facies can be distinguished respectively by their acid or alkaline reaction. The boundary is drawn where the pH of the soil is 7.0, which in this area is at an average altitude of about 7,000 feet (pl. 2, fig. 19). Diagrammatic profiles of typical Pedalfer and Pedocal facies on well-drained dioritic parent material are given in figure 54.

PEDALFER FACIES

The Pedalfer facies, above about 7,000 feet, was seen on till, talus, alluvial-fan gravel, alluvial sand and silt, and eolian sand and silt of the lower member of the

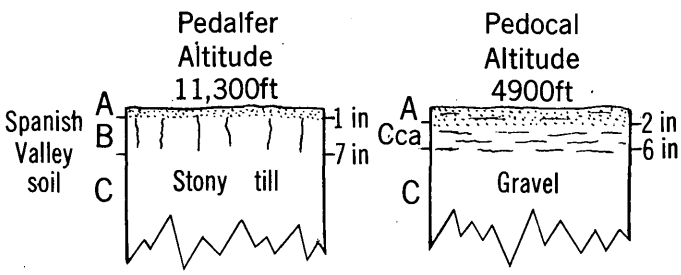

FIGURE 54.—Typical diagrammatic profiles of the two azonal facies of the Spanish Valley soil, showing their general character and thickness.

Gold Basin formation. Typical profiles are given in sections 24, 42, and 43.

Local variations in the facies reflect chiefly differences in slope, drainage, vegetation, and lithologic characteristics or texture of the parent deposits. The A horizon is about 1 to 6 inches thick and is loose, friable, and structureless. It is commonly dark gray to black under spruce, and more brownish under tundra vegetation, meadow, or aspen. The reaction (pH) tends to be only slightly acid under tundra, in many places less acid than the parent mantle. Under spruce, the reaction tends to be moderately to strongly acid. A whitish strongly acid A_2 subhorizon, generally less than half an inch thick, is locally present under spruce.

The B horizon, though locally lacking, tends to be 4 to 6 inches thick (table 7, p. 39), brown to dark brown (7.5*YR*–10*YR* 5/3–5/4), loose to friable, and structureless. Clay illuviation was not discernible. The reaction ranges from slightly acid (pH 6.0–6.5) at higher altitudes to neutral (pH 6.5–7.0) at about 7,000 feet.

PEDOCAL FACIES

The Pedocal facies, below about 7,000 feet, is considered azonal because, although the parent mantle beneath the A horizon is calcareous and alkaline, a Cca horizon cannot be clearly delineated. The facies was observed on alluvial gravel, alluvial sand and silt, and eolian sand and silt. Typical profiles are given in sections 28, 40, 44, 45, and 46.

Local variations in the facies are slight, and are chiefly due to differences in slope, drainage, vegetation, or parent mantle. The A horizon ranges in thickness from about 2 inches where well drained at time of origin to about 2 feet where poorly drained. It is commonly gray to brown, varying in hue with the parent mantle. The horizon is structureless to weakly platy and loose to friable (table 9, p. 42; table 10, p. 43). Its reaction ranges from neutral at about 7,000 feet to moderately alkaline (pH 8.0) at about 4,000 feet. Slight accumulations of calcium carbonate locally form films on rock fragments or the walls of structural openings. The reaction of the parent mantle ranges with altitude like that of the A horizon.

SUMMARY OF THE CHARACTERISTICS OF THE SPANISH VALLEY SOIL

The Spanish Valley soil displays characteristics that set it apart from other soils in the area.

1. The average altitude of the boundary between the Pedalfer and Pedocal facies is lower than that separating the Brown Podzolic and Brown Forest facies of all other soils.
2. A B horizon is restricted to the Pedalfer facies. Its lower altitude limit is higher than that of the B horizon of any other soil.
3. The B horizon ranges from 4 to 6 inches in maximum thickness, which is less than any other soil except possibly the Pack Creek.
4. The range of color of the B horizon is generally similar to that of the B horizon of Brown Podzolic facies of the Pack Creek and Castle Creek soils.
5. The B horizon is structureless, loose to friable, and has no discernible clay accumulation.
6. The reaction (pH) of the B horizon ranges from about as low as 5.5 at higher altitudes to about 7.0 at 7,000 feet—less acid than in any other soil at any given altitude (fig. 60).
7. Though there is no distinct Cca horizon, the pH of the upper few inches of the profile below 7,000 feet ranges from 7.0 to 8.0.
8. The reaction (pH) of both the A horizon and the underlying C horizon ranges from about 7.0 at an altitude of about 7,000 feet to about 8.0 at altitudes below 4,500 feet. At any given altitude below 7,000 feet, the pH of the profile tends to be lower than that of the Cca horizon of all other soils (fig. 60).

EROSION SURFACE BETWEEN THE LOWER AND UPPER MEMBERS OF THE GOLD BASIN FORMATION

Arroyos as much as 30 feet deep were cut in the lower member of the Gold Basin formation before the upper member was deposited. Dissection was greatest in lower Castle Valley and Spanish Valley (pl. 5) and lessened headward to the mouths of canyons. Within the mountains, alluvium of the upper member rests conformably, or nearly so, on the lower member. All the erosion appears later than the Spanish Valley soil.

MODERN SOIL DEVELOPMENT ON THE UPPER MEMBER OF THE GOLD BASIN FORMATION

The upper member of the Gold Basin formation, where still being deposited or reworked, shows no evidence of soil development. However, many inactive parts of this member, such as alluvial or eolian sand and silt or fine-textured talus, have a faint humus horizon and support vegetation. The pH of this faint soil on flood plains ranges from 6.0 at 11,000 feet to 8.0 at 4,000 feet and is 7.0 at an average altitude of 6,400 feet, the probable boundary between modern Pedalfer and Pedocal soil-forming processes.

CORRELATION

Correlations of Quaternary deposits in the Rocky Mountains and adjacent regions have been offered by many geologists, most recently by Ray (1940), Flint (1947, p. 302–303), and Holmes and Moss (1955). For purposes of this report, a method using soils as criteria for correlation will be described and applied to a few key areas. It should not be inferred, however, because of the emphasis on soils that they are more significant criteria than others, for all commonly accepted criteria available have been given careful consideration.

SOIL-STRATIGRAPHIC CORRELATION

Reliable correlation is believed possible by comparing the relative degree of development and geologic succession of soils in sequences of Quaternary deposits from different areas. This hypothesis rests on two assumptions: (1) that the major factors in soil development are, directly or indirectly, climate and the duration thereof; (2) that climatic fluctuations during the Quaternary were synchronous throughout the Rocky Mountains and adjacent regions, though individual soil-forming optima were probably shorter and generally cooler at northern latitudes than at southern. If these assumptions are valid, it follows that geologically distinct soils should be present throughout the region. The problem is how to identify and correlate them.

In the La Sal Mountains, the facies of each geologically distinct soil can be traced from one to another, leaving no doubt as to their correlation. However, detailed comparison of like facies of these soils discloses notable differences in thickness, color, structure, consistence, and pH (fig. 55). These data, taken together, define "degree of development" as used in this report, and comparison of them suggests that the relative degree of development of each soil is constant throughout all its facies. To test this conclusion, all available data for each characteristic of the B and Cca horizons of well-drained profiles of each of three soils were compiled as a composite, without regard for facies, vegetation, or for texture, lithologic characteristics, or genesis of the parent mantle (figs. 56–61). Graphs drawn from the data show that the characteristics of each soil have a distinctive range, differentiating it from all other soils. Thus they confirm the conclusion reached for the individual facies that relative development is the same for all facies of each geologically distinct soil.

In the La Sal Mountains, where the relief is about 8,500 feet, four facies are telescoped into a horizontal distance of about 12 miles. A traverse across four such facies in the central United States is well over 1,000 miles. In the La Sal Mountains, the succession of soils in terms of relative development is, from oldest to youngest, very strong, very strong, very strong, weak, strong, weak, moderate, and very weak. Such a succession should occur equally in the larger region and thus provide a basis for correlation.

Soils so correlated need not look alike, for appearance varies with facies and other factors. Conversely, soils that look alike are not necessarily correlative, for a soil that is strongly developed with respect to others in a local succession may resemble one that is but weakly developed with respect to those in its local succession. As complete a succession as possible is therefore necessary to insure reliable correlation.

CORRELATION WITHIN THE ROCKY MOUNTAIN REGION

Correlation of the Quaternary deposits of the La Sal Mountains with those of certain well-known areas in the Rocky Mountain region is shown in table 11. The basis for correlation with each area is given briefly below.

SAN JUAN MOUNTAINS, COLO.

Atwood and Mather (1932) recognized three stages of glaciation: the Cerro, the Durango, and the Wisconsin. Both the Durango and Wisconsin stages as considered by Atwood and Mather are now believed to include two substages, and deposits of two younger Recent glaciations have been identified (Richmond, 1954).

Till of the Cerro stage consists of sheetlike deposits, lacking morainal topography, that cap upland ridges and divides. It has a thick, very strongly developed profile of weathering as compared with soils on younger tills in the area. In all these respects it resembles the two older tills of the Harpole Mesa formation in the La Sal Mountains. It differs from the younger till of that formation primarily in that it has not been found in the canyons.

Till of the Durango stage includes the outermost moraines in the canyons and, in places, comprises two moraines with associated outwash deposits that appear to represent two advances of the ice separated by an interval of erosion. Both moraines have a relatively strong relict soil and resemble moraines of the two tills of the Placer Creek formation in the La Sal Mountains.

The so-called Wisconsin till includes two well-preserved, bouldery moraines that lie upstream from moraines of the Durango stage and appear to represent two ice advances. They have a relatively moderately developed soil, as do the two tills of the Beaver Basin formation in the La Sal Mountains.

Deposits of two younger glacial advances are widespread in the cirques of the San Juan Mountains. Those of the older advance include small moraines and rock glaciers which have a very weak soil, compared with that on the so-called Wisconsin till, and support scrub spruce and grassy tundra. They thus resemble the lower member of the Gold Basin formation in the La Sal Mountains. These deposits are overlapped by

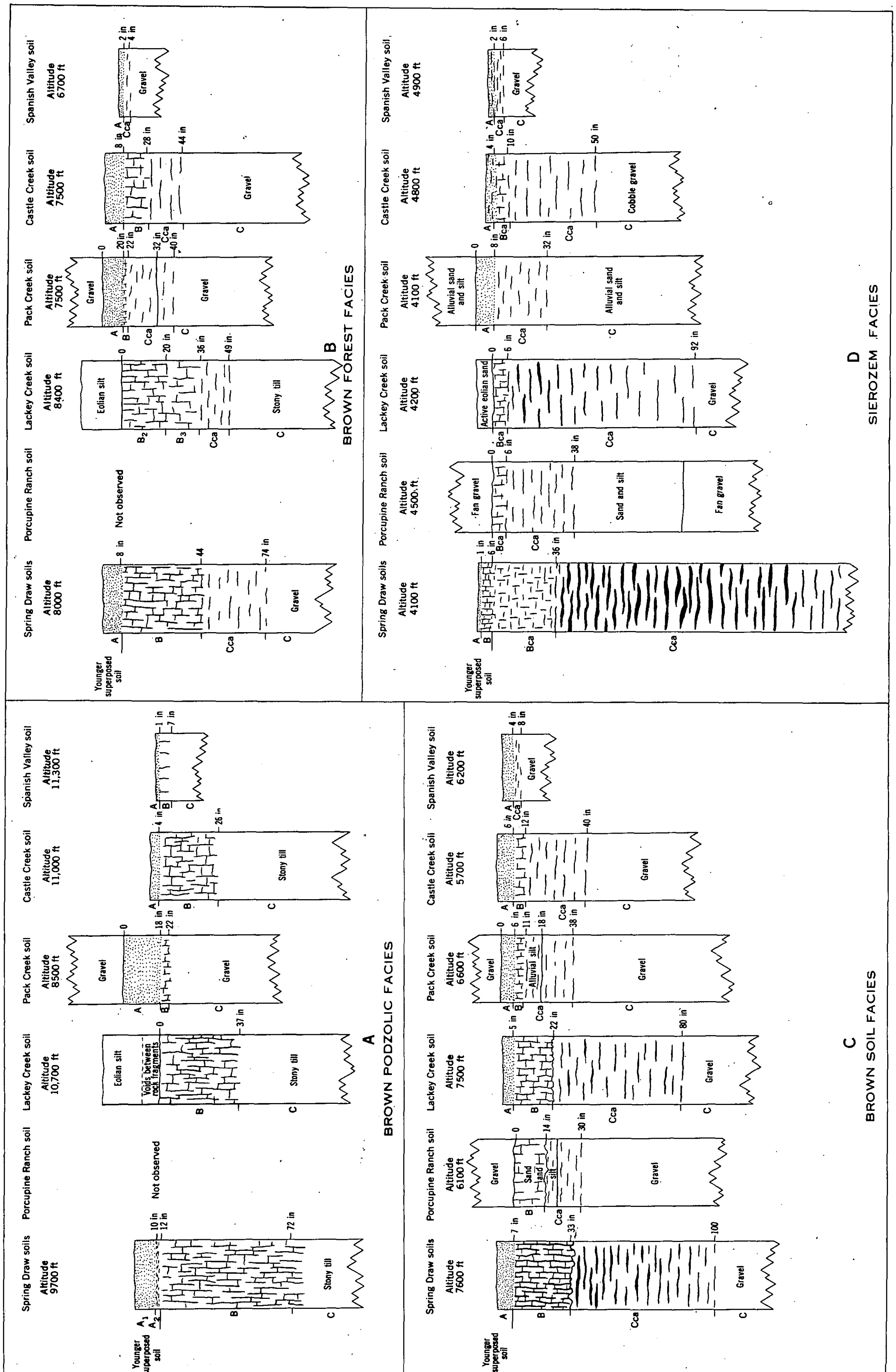

FIGURE 55.—Comparison of the general character and thickness of facies of soils of different geologic age in the La Sal Mountains, Utah. *A*, Brown Podzolic facies; *B*, Brown Forest facies; *C*, Brown soil facies; *D*, Sierozem facies.

TABLE 11.—*Correlation of Quaternary deposits of the La Sal Mountains*

Series	Stage	Midcontinent region time-stratigraphic standard	La Sal Mountains, Utah		San Juan Mountains, Colo		Front Range, Cache La Poudre River, Colo	Wind River Mountains, Wyo		Hopi Country, Arizona	Nebraska	Kansas	
			This report		Modified after Atwood and Mather (1932), Richmond (1954)		Modified after Bryan and Ray (1940), Ray (1940)	Modified after Blackwelder (1915), Richmond (1948), Moss (1949, 1951)		Modified after Hack (1942)	Modified after Schultz, Loeninghoener, and Frankforter (1951)	After Frye and Leonard (1952)	
Recent series			Gold Basin formation	Upper member		Rock glaciers	Modern moraines R2		Modern moraines	Naha formation	Flood plain deposits, Soil Z' alluvium		Flood plain and Recent low terraces
			Gold Basin formation	Spanish Valley soil		Very weak soil	Very weak soil		Very weak soil	Very weak soil	Soil Z		Flood plain and Recent low terraces
			Gold Basin formation	Lower member		Moraines or rock glaciers	Type Sprague moraine R1		Temple Lake stage	Tsegi formation	Alluvium		Flood plain and Recent low terraces
				Castle Creek soil		Modern soil	Moderate soil		Moderate soil	Moderate soil	Soil Y		Post-Bignell soil
Pleistocene series	Wisconsin stage	Late Wisconsin	Beaver Basin formation	Upper member	Wisconsin stage	Upper till	Type Long Draw deposit Moraine at Long Draw Reservoir W4	Pinedale stage	Upper till	Jeddito formation	Bignell	Sanborn formation	Bignell
				Pack Creek soil							Soil YY		Leached zone
				Lower member		Lower till	Type Corral Creek moraine W3		Lower till		loess		member
		Middle Wisconsin		Lackey Creek soil	Durango stage	Strong soil	Strong soil	Bull Lake stage	Strong soil		Brady soil (soil X)		Brady soil
		Early Wisconsin	Placer Creek formation	Upper member		Upper till	Home moraine W2		Upper till		Peorian		Peoria
				Porcupine Ranch soil							Soil W		Leached zone
				Lower member		Lower till	Pre-Home deposits W1		Lower till		loess		member
	Sangamon (?) stage		Harpole Mesa formation	Upper Spring Draw soil				Buffalo stage	Very strong soil		Sangamon soil		Sangamon soil
	Illinoian (?) stage			Upper member					Post-canyon till (?)		Loveland loess		Loveland member
	Yarmouth (?) stage			Middle Spring Draw soil	Very strong soil		Very strong soil				Yarmouth soil		Yarmouth soil
	Kansan (?) stage			Middle member	Cerro stage		Prairie Divide till		Pre-canyon till (?)		Kansan till		Kansan till
	Aftonian (?) stage			Lower Spring Draw soil		Till					Aftonian soil		Aftonian soil
	Nebraskan (?) stage			Lower member					Pre-canyon till (?)		Nebraskan till		Nebraskan till

fresh rock glaciers of the most recent glacial episode, many of which were called rock streams by Atwood and Mather and ascribed to landslides. These deposits, though locally lichen covered, bear no soil. They appear stagnant, but they grade headward into active talus as do rock glaciers of the upper member of the Gold Basin formation in the La Sal Mountains.

The succession of soils in the San Juan Mountains, when compared in terms of relative development with that in the La Sal Mountains, seems to be reasonably correlated (table 11) if the disconformities separating the two advances of tills of the Durango and the so-called Wisconsin stages are considered equivalent to the weak Porcupine Ranch and Pack Creek soils.

FRONT RANGE, COLO.

A sequence of glacial deposits, widely used in correlation in the Southern Rocky Mountains, is that along the Cache la Poudre River in the Front Range of Colorado. Here, Bryan and Ray (1940; Ray, 1940) recognized one precanyon glaciation, the Prairie Divide, of pre-Wisconsin age, and five postcanyon glaciations of Wisconsin and possibly Recent age. A reexamination of the area by the writer suggests some revision of their succession.

Till of the Prairie Divide stage of Bryan and Ray (1940) has been recognized only on intercanyon divides and has a very thick well-developed soil. It thus resembles the lower and middle members of the Harpole Mesa formation, but it differs from the upper member because it is not found in the canyons.

The oldest canyon advance, the pre-Home or W_1 of Bryan and Ray (1940), is represented only by ice marginal channels and outwash along the Cache la Poudre River (fig. 62). The outwash has a relatively strongly developed soil. The Home, or W_2 moraine, bears a similar soil, mantled by younger eolian sand and silt. These deposits of the pre-Home and Home advances resemble the two members of the Placer Creek formation. The outwash deposits of the two advances are clearly separated by erosion, but no buried soil has been found between them.

The lower of two moraines on Corral Creek (fig. 62) is the type Corral Creek or W_3 moraine of Ray (1940). The upper moraine is associated with a pitted outwash

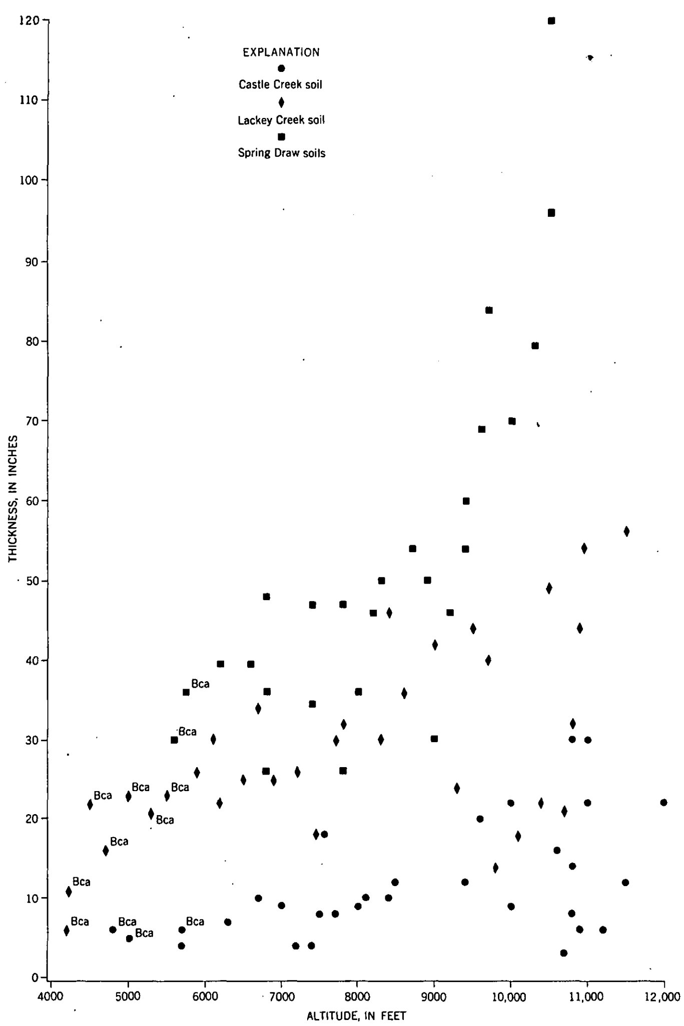

FIGURE 56.—Range in maximum thickness of B or Bca horizon with altitude in soils of different geologic age in the La Sal Mountains, Utah.

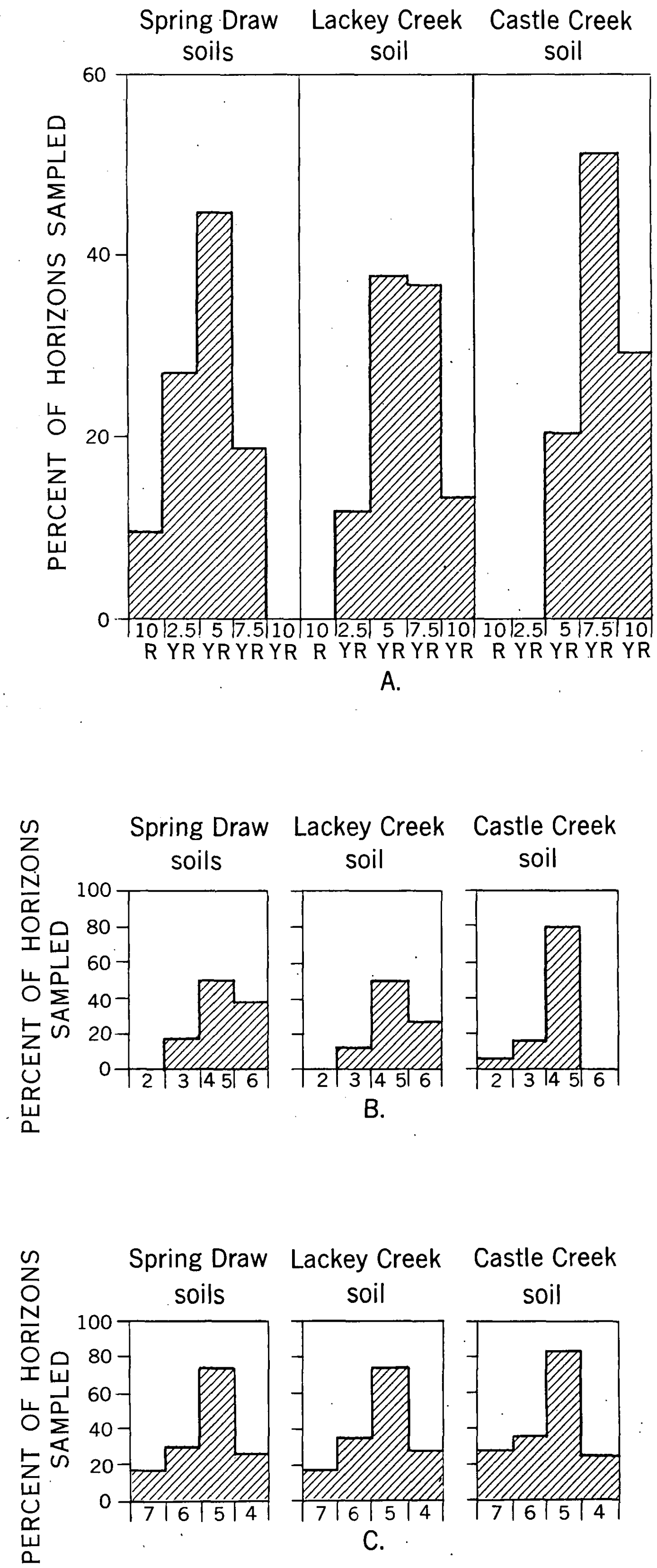

FIGURE 57.—Range in color properties of B horizon of soils of different geologic age in the La Sal Mountains, Utah. *A*, Range in hue of B horizon; *B*, range in chroma of B horizon; *C*, range in color value of B horizon.

plain and was identified by Ray (1940) as his Long Draw or W_4 advance. The writer believes it to be somewhat older than the type Long Draw deposits as shown below. Both moraines have a moderately developed soil, as do the two members of the Beaver Basin formation in the La Sal Mountains, with which they are here correlated. A similar pair of moraines with the same soil lie in the lower sector of Long Draw. The lower moraine was mapped as the Corral Creek advance by Ray. The upper moraine lies at the foot of Long Draw Reservoir and was seemingly not taken into consideration by Ray. It marks the terminus of an advance equivalent to the upper moraine on Corral Creek and is somewhat older than the type Long Draw deposit upstream.

The type deposit of the Long Draw or W_4 advance of Ray lies along Long Draw in the saddle of La Poudre Pass (fig. 62). It consists of hummocky, well-bedded, extensively slumped, ice-contact deposits of sand and

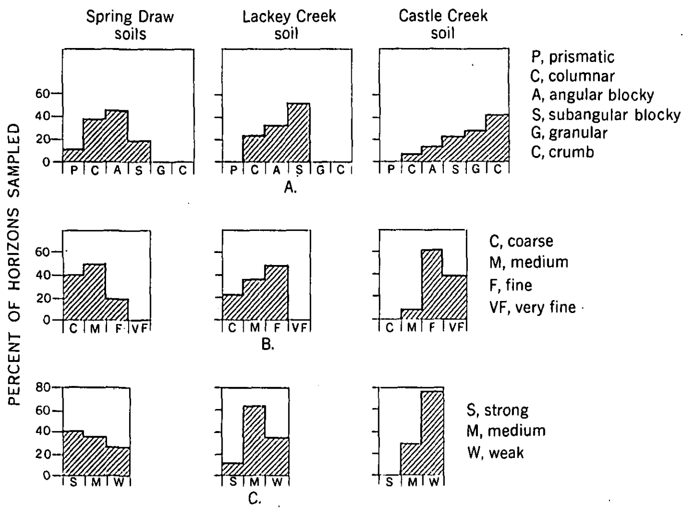

FIGURE 58.—Range in structural properties of B horizon of soils of different geologic age in the La Sal Mountains, Utah. *A*, Range in type of structure; *B*, range in class of structure; *C*, range in grade of structure.

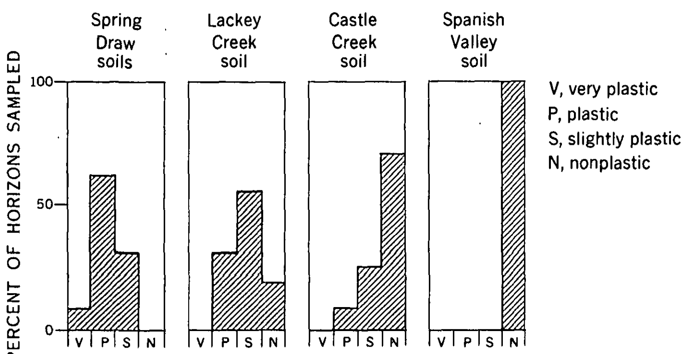

FIGURE 59.—Range in relative plasticity of B horizon when wet in soils of different geologic age in the La Sal Mountains, Utah.

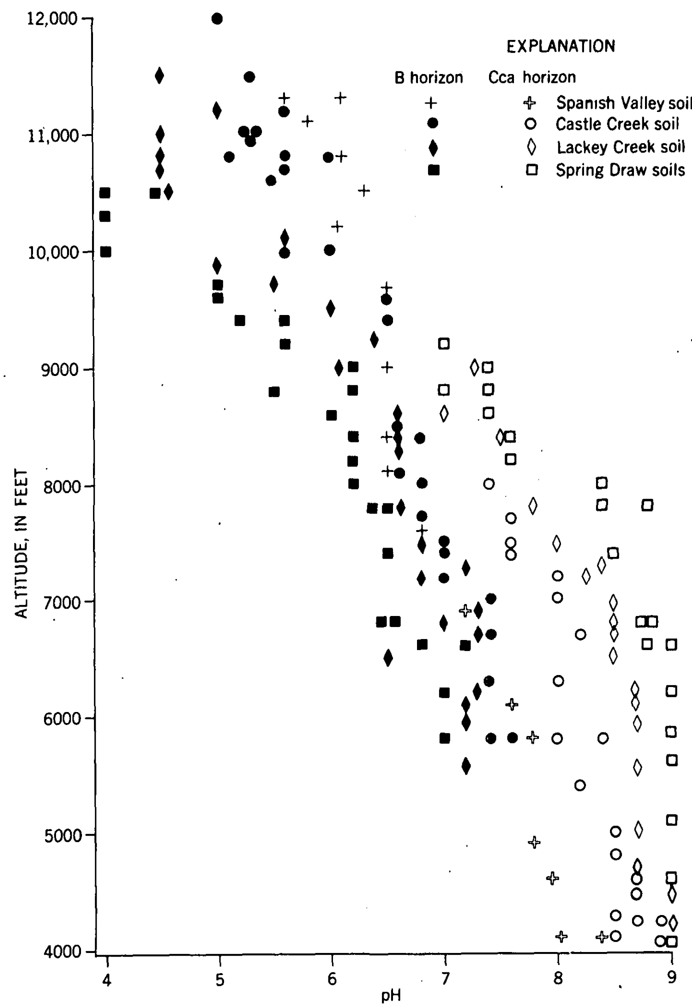

FIGURE 60.—Distribution of pH of B and Cca horizons of soils of different geologic age with altitude in the La Sal Mountains, Utah.

gravel that appear to have formed around blocks of stagnant ice left during a temporary halt in the recession of the ice from the moraine at the Long Draw Reservoir.

The deposit has a moderately developed soil like that on the moraines downstream along Long Draw and on Corral Creek. Radiocarbon analysis by the U.S. Geological Survey Laboratory (sample W–145) of wood from near the base of a peat bog in the deposit yielded an age of 6,170±240 years (Rubin and Suess, 1955, p. 485). The deposit is, therefore, older than the "altithermal interval" or "postglacial optimum."

A small rock glacier (protalus of Ray, 1940) lies at the head of Corral Creek (fig. 62). It was identified by Ray as belonging to his Sprague or W_5 advance. The deposit has a very weak azonal soil, supports a tundra and scrub-spruce vegetation, and is overlapped by seasonally active, modern talus with no soil. It thus resembles the lower member of the Gold Basin formation.

The type Sprague moraine, which Ray believed to represent the youngest glacial advance in the region, is in Rocky Mountain National Park in a cirque north of the head of Spruce Canyon. It lies below the lower of two lakes at the foot of Sprague Glacier. Like the rock glacier on Corral Creek and those of the lower member of the Gold Basin formation in the La Sal Mountains, it supports a tundra vegetation and has a weak azonal soil. Below Sprague Glacier, at the upper end of the upper lake is a small barren moraine with no soil that is distinctly younger than the type Sprague moraine. It is a deposit of the modern glacier and represents a second Recent re-advance. Moraines of this re-advance are present at the heads of many other canyons in Rocky Mountain National Park below the snouts of modern glaciers. Their freshness and lack of soil compares favorably with the moraine and rock glaciers of the upper member of the Gold Basin formation.

Comparison of the succession of soils in the Cache la Poudre area with that in the La Sal Mountains suggests the correlation shown in table 11.

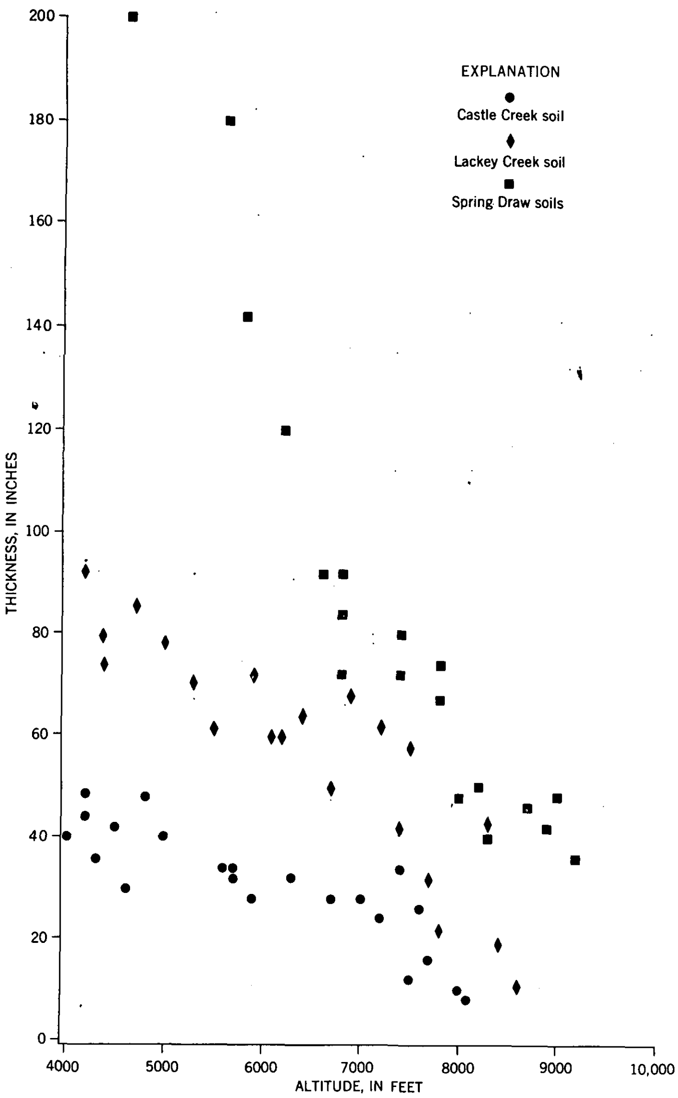

FIGURE 61.—Range in maximum thickness of Cca horizon in soils of different geologic age in the La Sal Mountains, Utah.

WIND RIVER MOUNTAINS, WYO.

In the Wind River Mountains three stages of glaciation, the Buffalo, the Bull Lake, and the Pinedale, were defined and clearly described by Blackwelder (1915). Till of the Buffalo stage includes sheetlike deposits that lack morainal topography and have a very thick and strongly developed soil. Blackwelder described the deposits as the product of a single glacial advance, but he recognized some indications that they might represent two advances, and two precanyon, gravel-capped terraces have been observed to grade into till of the Buffalo stage on interfluves along the northeast flank of the mountains (Richmond, 1948). Till of the Buffalo stage may therefore include deposits of two precanyon advances. Recently, deeply weathered Buffalo drift has been observed in canyons on the southwest flank of the range, and it is believed to be of postcanyon age (Moss, 1951a; Holmes, 1951; Holmes and Moss, 1955). Though more detailed observations are needed, it is probable that till of the Buffalo stage may actually include deposits of three glaciations, two precanyon and one postcanyon, as the Harpole Mesa formation with which it is here correlated.

Till of the Bull Lake stage, as defined by Blackwelder (1915), comprises large and well-developed moraines that have a mature aspect and are commonly the outermost in the canyons. They are deeply dissected by axial streams and retain no lakes. A relatively strong soil is formed on them. Two distinct groups of moraines, each graded to separate outwash terraces, have been distinguished (Richmond, 1948; Moss, 1949a, 1951a; Holmes, 1951) and are believed to represent two separate glaciations (Richmond, 1948). Relict soil profiles on both groups of moraines are similar. The relative stratigraphic position of these moraines and the relatively strong soil on them suggest their equivalence to the tills of the two members of the Placer Creek formation (table 11).

Till of the Pinedale stage comprises moraines that generally lie upstream from moraines of the Bull Lake stage, though in some canyons they extend through and beyond them. The moraines are smaller, rougher, more bouldery, and less dissected than moraines of the Bull Lake stage. The soil on them is relatively only moderately developed. Two distinct groups of these moraines, each graded to separate outwash terraces, have been distinguished (Richmond, 1948; Moss, 1951a; Holmes, 1951), and they probably represent two separate glaciations (Richmond, 1948). The soil on both groups and on related deposits is similar. Its relatively moderate development suggests that the moraines are equivalent to the two members of the Beaver Basin formation (table 11).

Two ice advances, younger than the Pinedale, have been recognized in the Wind River Mountains. The older, first recognized by Hack (1943), was named the Temple Lake from a locality in the southern part of the mountains (Moss, 1951b). It is equivalent to the ice advance called Pinedale III in the northern part (Richmond, 1948). The younger advance is represented by fresh moraines, called cirque moraines by Moss (1951a), in front of modern glaciers or in cirques from which the ice has only recently disappeared.

The Temple Lake moraines are small, very bouldery deposits in, or just below, the cirques at altitudes between 1,000 and 1,500 feet higher than the upper moraines of the Pinedale stage. They have a very weak soil compared with older tills nearby, and they support a tundra and scrub-spruce vegetation.

Most writers (Hack 1943; Richmond, 1948; Moss, 1949b, 1951a, 1951b; Holmes, 1951) have correlated the Temple Lake advance with the Long Draw or W_4 substage of Bryan and Ray (1940) and indicated that

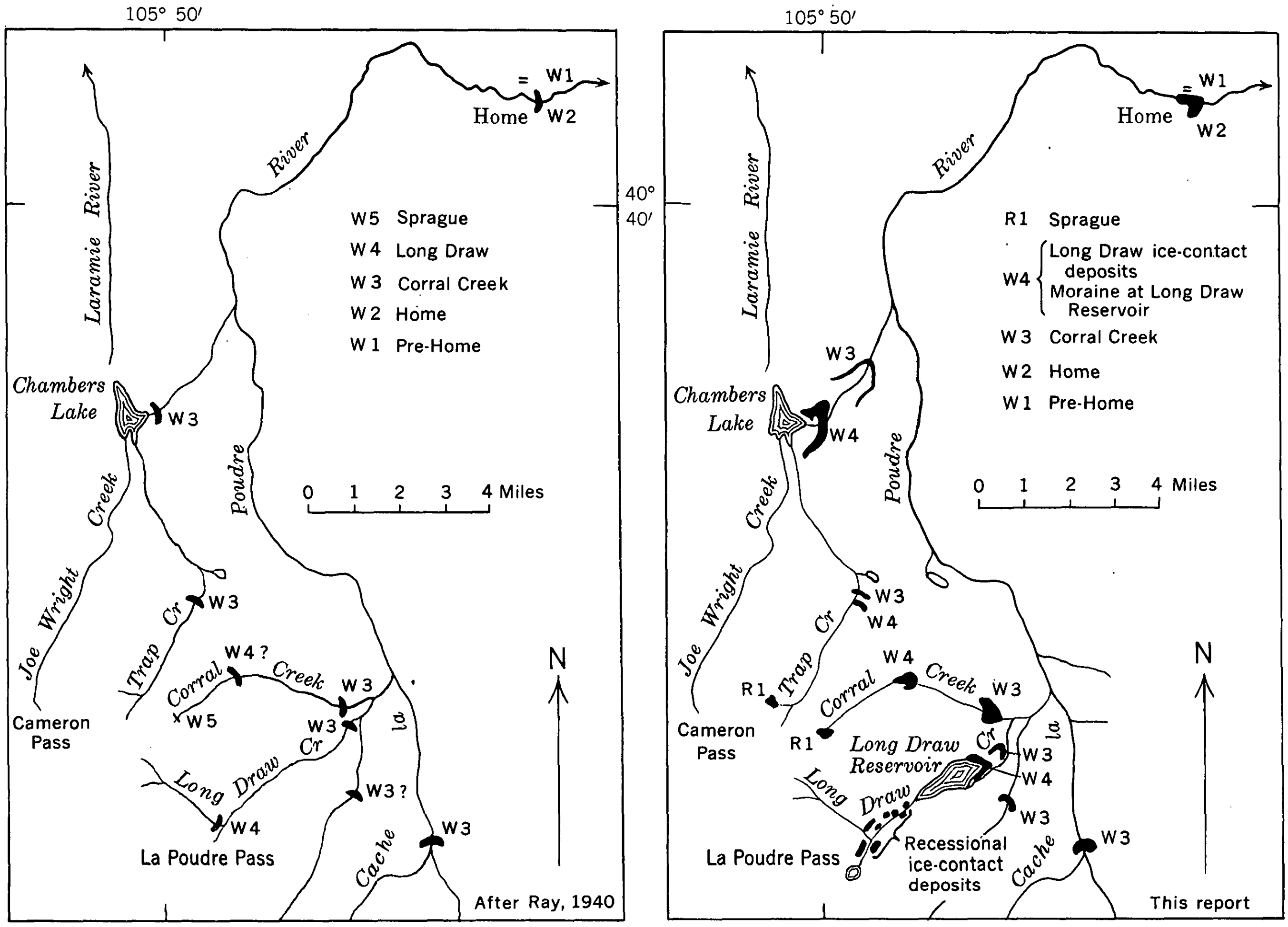

FIGURE 62.—Sketch maps comparing interpretations of moraines in the Cache la Poudre drainage system.

it was older than the "altithermal" interval or "climatic optimum." The relative development of its soil, however, suggests equivalence with the lower member of the Gold Basin formation and with the Sprague moraine of Ray (1940) at its type locality. The radiocarbon age of 2,800±200 years of the lower member of the Gold Basin formation indicates that these moraines are younger than the "altithermal" interval.

The modern moraines appear fresh and lack soil. They support no vegetation, their boulders are very unstable, and some contained stagnant ice when examined by the writer in 1940. They appear equivalent in every way to moraines of the post-Sprague Recent advance of the Front Range of Colorado and to those of the upper member of the Gold Basin formation in the La Sal Mountains (table 11).

CORRELATION WITH THE ALLUVIAL DEPOSITS OF THE HOPI COUNTRY

The alluvial deposits in the La Sal Mountains can be reasonably well correlated with those in the Hopi Country of Arizona (Hack, 1942) on several lines of evidence.

Alluvium of the Beaver Basin formation in the La Sal Mountains is correlated with the Jeddito formation of Hack (1942) in the Hopi Country (table 11). Both are coarse gravels in similar stratigraphic settings, cut by arroyos, and overlain conformably by extensive eolian deposits which, in the Hopi Country, were attributed to the "climatic optimum" (Hack, 1942). The soils on both are similar. The alluvium of the Beaver Basin formation differs from the Jeddito in that it commonly rests on older alluvium (Placer Creek) rather than on bedrock valley floors. It also comprises two members separated by a weak soil or by a disconformity not found in the Jeddito formation. No extinct vertebrates, such as occur in the Jeddito formation, have been found in the Beaver Basin, and neither formation contains artifacts.

The lower member of the Gold Basin formation is correlated with the Tsegi formation of Hack (1942) of the Hopi Country (table 11). From geologic and archeologic criteria, Hack has inferred that the Tsegi

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formation was formed between 3000 B. C. and A. D. 1200. Charcoal from the lower member of the Gold Basin formation has an age of 2,800±200 years (Rubin and Suess, 1955), which places it at about 900 B. C. Both deposits consist predominantly of light-red to brown well-bedded fine-grained sand and silt. Both occur in, and locally fill, channels in older alluvium. The lower member of the Gold Basin formation, although a single unit upstream, contains in lower valleys a local unconformity or faint bumus zone like that in the Tsegi formation. It also contains modern vertebrates and, like the Tsegi, hearth sites and charcoal, though hearths have been reported from only the upper part of the Tsegi alluvium (Hack, 1942). A pre-pottery stone culture was found in the lower member of the Gold Basin formation and extensively on its surface (Hunt, A. P., 1954). The Spanish Valley soil is weakly developed and azonal, as the soil on the Tsegi formation. The lower member of the Gold Basin formation, like the Tsegi, is cut by arroyos that contain locally a younger terraced alluvium. In the La Sal Mountains, this younger alluvium is the upper member of the Gold Basin formation. It is correlated with the Naha formation of Hack (1941) of the Hopi Country (table 11). Both consist of fine sand and silt, contain pottery, and bear little or no soil.

NEBRASKA

The stratigraphy of the loess sheets of Pleistocene age of Nebraska has been intensively studied (Lugn, 1934; 1935, 1939; Schultz and Stout, 1945, 1948; Lueninghoener, 1947; Frankforter, 1950; Schultz, Lueninghoener, and Frankforter, 1948, 1951; Thorp, Johnson, and Reed, 1951; Schultz, Reed, and Lugn, 1951). The succession shown in table 8 is modified after Schultz, Lueninghoener, and Frankforter (1951). The Afton, Yarmouth, and Sangamon soils, as described by Thorp, Johnson, and Reed (1951), are all very strongly developed and generally similar. Each is dated by a well-established fauna. They are tentatively correlated with the lower, middle and upper Spring Draw soils in the La Sal Mountains.

Above the Sangamon soil, the Peorian loess is locally separated into two units by an "infantile" soil (soil W of Schultz, Lueninghoener, and Frankforter, 1951), much as the Placer Creek formation is separated into members by the Porcupine Ranch soil. A relatively strongly developed soil, the Brady soil, or soil X, is formed on the Peorian loess. It was defined stratigraphically by Schultz and Stout (1945, 1948) and has been described by Thorp, Johnson, and Reed (1951). In relative development and geologic position it resembles the Lackey Creek soil in the La Sal Mountains.

The Bignell loess, overlying the Brady soil, also locally contains a weakly developed "infantile" soil (soil YY of Schultz, Lueninghoener, and Frankforter, 1951) and has a moderately developed post-Bignell soil (soil Y) at its surface. In these respects it resembles the Beaver Basin formation.

Two generations of alluvium younger than the Bignell loess and older than the modern flood plains are present in Nebraska (Schultz and Stout, 1948; Schultz, Loeninghoener, and Frankforter, 1951). The older contains hearth sites, but no pottery, and bears a very weak azonal soil (soil Z). It is believed equivalent to the lower member of the Gold Basin formation and to the Tsegi formation of the Hopi Country. The younger alluvium contains pottery and has only a faintly humic horizon (soil Z^1). Together with the flood-plain deposits, it is correlated with the upper member of the Gold Basin formation.

KANSAS

A similar succession of deposits and soils has been independently recognized in Kansas (Frye and Hibbard, 1941; Hibbard, 1944, 1948, and 1949; Frye, 1945, 1946, 1948, 1949, 1951; Frye and Fent, 1947; Frye, Swineford, and Leonard, A. B., 1948; Frye and Leonard, A. R., 1949; Frye and Leonard, A. B., 1949, 1951, 1952; Leonard, A. B., 1952). The sucession in table 11 is adapted after Frye and Leonard, A. B. (1952). The Afton, Yarmouth, and Sangamon soils are all very strongly developed and dated faunally as in Nebraska. The Peoria loess contains two distinct molluscan faunal zones, described by Leonard, A. B. (1952), and, in places, a leached horizon that may be very weak soil. The Brady soil is relatively strong. The overlying Bignell loess also contains a leached horizon which may be a weak soil. The post-Bignell soil is moderately developed, and there are younger alluvial terrace deposits on which very weak soils are formed.

The succession of soils is the same in terms of relative development as in Nebraska and may be similarly correlated with the succession in the La Sal Mountains (table 11).

CORRELATION WITH THE MID-CONTINENT REGION

Precise correlation of the deposits in the La Sal Mountains with those of the standard Pleistocene stages of the upper Mississippi Valley is not possible at present. The Spring Draw soils may represent the Aftonian, Yarmouth, and Sanagamon stages; and the three members of the Harpole Mesa formation may represent the Nebraskan, Kansan, and Illinoian stages. That the upper part of the middle member is locally of Yarmouth age is indicated by the similarities of the ash bed in it to the Pearlette volcanic ash bed of Kansas as shown by Powers (p. 34, this report). The Placer Creek formation is possibly early Wisconsin and the Beaver Basin formation probably late Wisconsin. The Gold Basin formation is clearly of Recent age, but no correlative stratigraphy is known from the glaciated sector of the mid-continent region.

RELATION OF SOILS AND SOIL FACIES TO SOIL SERIES OF U.S. DEPARTMENT OF AGRICULTURE

Unpublished studies of the soils near La Sal and Monticello by the U.S. Department of Agriculture, under the direction of W. G. Harper, provide a basis for tentatively relating the soils as classified in this report with the soil series of the Department of Agriculture. These relations, shown in table 12, were established in part through field conferences with Mr. Harper.

TABLE 12.—*Relation of soils and soil facies to soil series*

This report		Department of Agriculture [1]	
Soil	Facies	Soil series	Soil-series description
Spanish Valley	Pedocal	Ackmen series.	Azonal soil on alluvial silt loam derived from sandstone and diorite. Noncalcareous; little organic matter.
Castle Creek	Brown Forest		
Spanish Valley	Pedocal	Pack series.	Azonal soil on alluvial silt loam derived from sandstone and diorite. High organic content; calcareous.
Castle Creek	Brown Forest		
Castle Creek	Brown soil	Vega series.	Azonal soil on alluvial silt loam derived from sandstone, diorite and loess; calcareous.
Castle Creek	Brown soil	Scorup series.	Azonal soil on alluvial loam over gravel; calcareous.
Spanish Valley	Pedocal	Shay series.	Intrazonal soil on alluvial silty clay derived from Mancos shale; calcareous.
Castle Creek	Sierozem		
Castle Creek	Brown soil	Tabiona series.	Brown soil on alluvial silt loam or silty clay loam; calcareous.
Lackey Creek	Sierozem	Blanding series.	Sierozem on loess.
Lackey Creek	Brown soil	Mellenthin series.	Brown soil on thick loess.
Castle Creek	Brown soil	Monticello series.	Chestnut soil on loess over sandstone.
Lackey Creek	Brown soil		
Lackey Creek	Brown soil	Abajo series.	Chestnut soil on gravel.
Spring Draw	Brown soil		

[1] W. G. Harper, written communication, 1953.

Some of the soil series embrace soils of more than one geologic age. For example, the Monticello soil series includes the Brown soil facies of both the Lackey Creek and Castle Creek soils, the Abajo soil series includes the Brown soil facies of the Spring Draw and Lackey Creek soils, and the Pack, Ackmen, and Shay soil series include both the Brown Forest facies of the Castle Creek soil and the Pedocal facies of the Spanish Valley soil. It will be noted that soil series described as azonal or intrazonal by the Department of Agriculture are related to the Castle Creek soil, which is described as zonal in this report. The profiles of these soils are azonal in having no marked horizon of clay accumulation, but they are considered zonal in this report because they have a horizon of calcium carbonate accumulation clearly set apart from an overlying horizon marked by partial leaching of calcium carbonate and slight accumulation of sesquioxides. Soil series correlated with the Spanish Valley soil are azonal, and their characteristics appear to depend more on differences in parent material and local environment than on regional soil-forming processes.

SUMMARY OF QUATERNARY HISTORY

The Quaternary period in the La Sal Mountains was characterized by a series of cycles during each of which the dominant geologic process changed progressively from sedimentation to a condition of slope stability and soil development followed by erosion. These changes were in response to widespread climatic changes that caused the succession of glacial and interglacial intervals.

THE PREGLACIAL LANDSCAPE

Little is known of the late Tertiary and earliest Quaternary record prior to glaciation. The general altitude of the region was probably lower and the relief less than today, though the size and shape of the mountains were probably about the same as they are now. The stocks and laccoliths had been exposed by erosion, and the plateau surface near the mountains had been largely stripped of Cretaceous and Tertiary strata.

The grabens beneath Spanish Valley and Castle Valley were formed some time in the Tertiary prior to intrusion and uplift of the mountains. Castle Valley, in fact, was a basin in which a conglomerate of late Tertiary(?) age accumulated. However, all topographic vestiges of such basins were gone by the beginning of Quaternary time. The conglomerate in Castle Valley was folded and a broad pediment surface was cut across it before the advance of the earliest recorded glaciers.

Other extensive pediment surfaces on the northeast and southwest flanks of the mountains were probably cut in late Tertiary or early Quaternary time prior to the onset of glaciation. Broad shallow valleys may have extended east and west from the mountains in the general vicinity of the present canyons. Drainage from the west flank of the mountains formed a large stream that flowed northwest to the Colorado River across the plateau east of the Spanish Valley graben and diagonally across the site of the present canyon of Mill Creek. The gradients of these upland streams probably became steeper near their confluence with the Colorado River, which appears to have been well established in its present canyon. The difference in altitude between the canyon rim and the oldest Quaternary terrace deposits below suggests that the canyon was about 800 feet deep at the beginning of Quaternary time.

The absence of saprolite of Tertiary age, such as is common in areas of igneous rocks throughout the Rocky Mountains, suggests either that it was removed by later erosion or that it was never formed because of erosion and vulcanism in the mountains while it was developing elsewhere.

HARPOLE MESA TIME

Harpole Mesa time is that required for the deposition of the Harpole Mesa formation. It comprised at least three major glaciations, tentatively correlated with the Nebraskan, Kansan, and Illinoian glaciations of the mid-continent region, and three interglacial intervals, tentatively correlated with the Aftonian, Yarmouth, and Sangamon interglacial intervals.

EARLY HARPOLE MESA TIME

During early Harpole Mesa time glaciers originated in V-shaped valleys in the higher mountains and spread across the surrounding plateaus and pediments as broad, relatively thin, lobate sheets. Their extent and outer limits can only be crudely estimated (pl. 6) but were probably like those of middle Harpole Mesa time, described below.

The volume of material contributed by the glaciers and by mass-wasting on the slopes caused a change in regimen of the streams from erosion to aggradation. Fills, as much as 150 feet thick, were deposited from the margin of the glaciers out over the pediments. However, alluvial deposits, only about 20 feet thick, along the Colorado River suggest that aggradation upstream represented steepening of gradients in response to increased load from headwater sources. The thickness of the fills suggests either that the material was supplied faster, or, more probably, that the interval of deposition was considerably longer than during any post-Harpole Mesa glaciation.

Eolian activity accompanied early Harpole Mesa glaciation and perhaps outlasted it, for eolian deposits of the lower member of the Harpole Mesa formation are not only interbedded with till and outwash of that formation but overlie these deposits conformably in several places.

The present troughs of Spanish Valley and Castle Valley, as well as the canyons which now radiate from the mountains, were not in existence. The plateaus adjacent to the mountains were drained by broad shallow valleys which debouched through short steep gorges into the canyon of the Colorado River. Some drainage lines crossed the sites of present canyons, and others lay in approximately their present position.

EARLY SPRING DRAW TIME

During early Spring Draw time fluvial deposition ceased, and the thick, very strongly developed lower Spring Draw soil was formed. Together, these events indicate that the glaciers must have disappeared entirely from the mountains. The character and distribution of facies of the soil suggest that the climate during the soil-forming optimum, though broadly similar to that of today, was probably somewhat warmer and wetter. In fact, it was probably warmer and wetter than during any post-Harpole Mesa soil-forming optimum. The thickness and relatively very strong degree of development of the soil further suggest that the soil-forming optimum was longer than those of post-Harpole Mesa soils.

Forests probably covered the mountains completely and the vegetation zones migrated upslope about as far as they did during the late Spring Draw interval, discussed below.

Erosion, which must have begun during soil development, was most effective after the soil-forming optimum during the onset of pluvial conditions prior to the next glaciation. Streams cut broad, relatively deep valleys, except on the south flank of South Mountain where an extensive compound pediment formed. The depth of the valleys ranged from about 150 to 250 feet in the mountains but decreased to 60 or 75 feet along the Colorado River. The pediment on the south flank of South Mountain was cut at a level about 200 feet below that of thick outwash and alluvial deposits laid down during early Harpole Mesa time.

Why broad valleys were cut in some parts of the area and pediments in others is not clear. Broad valleys tend to have formed along trunk streams heading in large basins in the northern and central parts of the mountains, whereas pediments formed on the south flank of the mountains downslope from relatively small drainage basins. Precipitation was probably less on the south flank of the mountains than elsewhere, and vegetation was more sparse. Under these conditions the dominance of sheet flood and slope wash as agents of erosion on the south flank may have favored the development of pediments in that area.

The relatively slight dissection along the Colorado River suggests that, regionally, increased precipitation was the major factor inducing erosion. The relatively large amount of dissection in the mountains, however, appears too great to be accounted for by climatic change alone. Possibly, it represents a delayed erosional response to late Tertiary or earlier Quaternary regional uplift that had not previously taken place in the mountains owing to the overloaded condition of the streams during early Harpole Mesa time. It might also represent a response to local doming of the mountains in early Spring Draw time.

The Castle Valley graben is believed to have subsided during early Spring Draw time, for gravel deposited during early Harpole Mesa time lies well below the level of gravel of the same age on Dobe Mesa north of the graben. Furthermore, the deposits in the graben are overlain conformably by gravel and till deposited during middle Harpole Mesa time. This condition, found nowhere else in the mapped area, is believed to have been made possible by subsidence of the graben in early Spring Draw time.

MIDDLE HARPOLE MESA TIME

Glaciers of middle Harpole Mesa time reoccupied the shallow cirques formed in early Harpole Mesa time and advanced down the broad valleys cut during early Spring Draw time, filling them and overflowing the divides to form lobes of piedmont ice on the plateaus. The outer limits of these glaciers can be clearly delineated in some places (pl. 6), but in others they cannot be distinguished from those of early Harpole Mesa time.

The ice appears to have covered about 85 square miles and to have averaged between 150 and 250 feet thick. Its maximum volume is estimated roughly to have been between 2.5 and 4.0 cubic miles.

The increase in volume of debris that was contributed to the streams by the glaciers and by mass-wasting of slopes in a periglacial environment caused a change in stream regimen from erosion to aggradation. Thick outwash gravels were deposited in broad valleys and downslope from the glaciers. Near the mountains these deposits are over 150 feet thick, suggesting either that the interval of deposition was relatively long or that the rate of deposition was relatively rapid as compared with those of post-Harpole Mesa glaciations. Farther away from the mountains and along the Colorado River, the deposits are only 20 to 30 feet thick, which suggests either that relatively little material was transported this far from the mountains or that the major streams were capable of carrying most of the material that reached them. In either event, streams heading in the mountains steepened their gradients by aggradation to a considerable extent.

Present day drainage was generally established by this time, except in a few places such as on Dobe Mesa and on the plateau northeast of Spanish Valley.

Although no eolian sand or colluvial deposits of middle Harpole Mesa age are known, volcanic ash from a source outside the region to the west accumulated in Fisher Valley and mass-wasting processes were presumably active.

MIDDLE SPRING DRAW TIME

Middle Spring Draw time, like its predecessor, was marked by complete disappearance of the glaciers, soil development, and a major episode of erosion.

The distribution and character of the middle Spring Draw soil show that the climate during the soil-forming optimum was like those of the early and late Spring Draw soil-forming optima. Slopes were probably stable and the mountains completely forested.

Though erosion probably began before soil development, maximum dissection clearly postdated the soil-forming optimum. Presumably it took place late in the interglacial interval under pluvial conditions prior to the next glaciation. Relatively narrow canyons as much as 450 feet deep, but averaging about 200 feet deep, were cut in the broad alluviated valleys of the previous cycle. Spanish Valley and Castle Valley were partly excavated. The canyon of the Colorado River was deepened about 100 feet. On the more arid south flank of South Mountain an extensive pediment was cut at levels ranging from 50 to 200 feet below the surface of the pediment fill of middle Harpole Mesa age.

Although the erosion was probably initiated by climatic changes that affected stream regimen, the depth of dissection may have been caused by regional uplift. The streams, moreover, failed to attain base level before late Harpole Mesa glaciation commenced. A similar episode of canyon-cutting occurred just before the last pre-Wisconsin glaciation in the Front Range of Colorado and in the Wind River Mountains of Wyoming.

It is probable that the graben underlying Castle Valley continued to subside during middle Spring Draw time, because alluvial deposits of middle Harpole Mesa age on the floor of the graben are 400 feet below those of the same age on its northern rim.

LATE HARPOLE MESA TIME

Late Harpole Mesa glaciers reoccupied the broad basinlike cirques of middle Harpole Mesa age, whose floors had been incised by V-shaped canyon heads in middle Spring Draw time, and advanced down the canyons. Only locally, as on the southeast rim of Dark Canyon Creek, did they overflow the intercanyon divides. The extent of these lobate tongues of ice can be better delineated than those of older glaciations (pl. 6) and appear to have attained an average lower limit of about 8,100 feet, not taking into account any uplift of the mountains in post-Harpole Mesa time. They covered roughly 50 square miles and averaged between 300 and 400 feet thick. Their maximum volume may be estimated at between 2.8 and 3.8 cubic miles, or about the same as that of the more extensive but thinner and less confined glaciers of middle Harpole Mesa age.

As during earlier glaciations, streams became overloaded with outwash and slope debris and began to aggrade. Cooling of the climate must have been ultimately responsible for this change, for it took place during a regional episode of downcutting.

Gradients along the major canyons were but little steepened by aggradation, however, for deposits both near the ice and along the Colorado River are only about 20 feet thick. In contrast, aggradation on the headward sectors of pediments along the south flank of South Mountain amounted to 150 feet in several places, owing possibly to the difference in gradient between the pediments and the canyon floors.

The few preserved periglacial deposits of the upper member of the Harpole Mesa formation afford some evidence as to the kinds of mass-wasting that accompanied glaciation. Solifluction was probably widespread, but frost rubble development was very local. Talus was probably abundant, especially in the cirques, although it is identified at only one locality. Slope wash was important below the lower limit of glaciation. No eolian deposits positively referable to late Harpole Mesa time were found, but presumably eolian activity was extensive.

LATE SPRING DRAW TIME

Late Spring Draw time commenced with the complete disappearance from the mountains of glaciers of late Harpole Mesa age, as indicated by the presence of the upper Spring Draw soil in the cirques. Analogy with the more complete record of younger interstadial intervals suggests that the early part of this time was probably characterized by local alluviation of fine-grained deposits, local arroyo-cutting, and widespread eolian activity. Slopes were stable during the soil-forming part of the interval, as indicated by the presence of the upper Spring Draw soil even on slopes as steep as 40°.

The range in facies of the soil, from Sierozem to Brown Podzolic, shows clearly that the climate was temperate, relatively warm and dry at low altitudes, relatively cool and wet at high altitudes, but at no time tropical. The sharp irregularly leached boundary between the Cca and B horizons of the Brown Forest and Brown soil facies suggests that a soil-forming environment favoring leaching of carbonate followed, or at least outlasted, that favoring carbonate accumulation. That these two processes did not terminate concurrently at different levels in the profile is indicated by the fact that leaching along soil structures extends throughout the Cca horizon and in its upper part encloses carbonate in the cores of peds. From this it is inferred that precipitation, one of the major factors influencing accumulation and leaching of carbonate, increased gradually during the soil-forming optimum. The upper limit of the Cca horizon of the Brown Forest facies (fig. 19) suggests that in the early part of the soil-forming optimum the influence of an environment favoring carbonate accumulation extended upslope to an average altitude of about 9,200 feet. The lower limit of the B horzon in the Brown soil facies suggests that in the latter part of the optimum the influence of an environment favoring leaching of carbonate extended downslope to an average altitude of about 6,000 feet.

Some comparison can be made between the climate during this soil-forming optimum and that of subsequent optima. The fact that the facies of the upper Spring Draw soil are the same as those of all younger soils indicates that climatic conditions during each soil-forming interval were at least broadly similar. However, the fact that the range in altitude of similar facies differs for each soil (fig. 19) suggests significant differences in their environments. Assuming that similar facies of distinct soils require similar climatic conditions for development, it nay be inferred that the range in altitude of facies of soils of different geologic age reflects the approximate position of their respective climatic zones. The soil map showing this distribution (pl. 2) provides a basis for inferring differences in climate between soil-forming intervals. For example, the fact that the average altitude of the pedalfer-pedocal boundary of the Spring Draw soils is higher than that of any subsequent soil suggests that the climate during these soil-forming optima was on the whole warmer than during any later optimum.

Comparison of the degree of development of any facies of the Spring Draw soils with like facies of others may permit inferring the relative duration of their soil-forming optima. If, as has been assumed, like facies require like climates, and if other environmental conditions can be shown to have been similar, a facies of a given soil that has a relatively stronger profile probably required a longer time for development than similar facies of different soils with weaker profiles. Facies of the upper Spring Draw soil are similar to like facies of the middle and lower Spring Draw soils, but are much stronger than like facies of any younger soils. The three Spring Draw soil-forming optima were thus probably of similar length, and were considerably longer than any later soil-forming optimum.

The mountains are presumed to have been completely forested in late Spring Draw time (table 13) because of the very strong development of the upper Spring Draw soil at altitudes as high as 10,500 feet. The higher

TABLE 13.—*Possible average altitude of timberline in the La Sal Mountains during Quaternary glacial and interglacial intervals*

Age	Glacial and interglacial intervals of this report	Inferred average altitude of timberline (feet)	Criteria
Recent	Present (1950)	11,000 to 11,500	Present range in upper limit of spruce.
	Late Gold Basin time	11,300(?)	Estimated.
	Spanish Valley time	11,500	Dead unburned trees above present timberline.
	Early Gold Basin time	11,000(?)	Estimated.
	Castle Creek time	12,000	Average upper limit of Brown Podzolic facies of Castle Creek soil.
Pleistocene	Beaver Basin time	10,000	11,500 ft upper limit of preservation of Lackey Creek soil. 8,500 ft average lower limit of frost rubble of Beaver Basin formation.
	Lackey Creek time	Mountains covered <12,700	Upland distribution and character of Brown Podzolic facies of Lackey Creek soil.
	Placer Creek time	9,500	10,500 ft upper limit of preservation of Spring Draw soil. 8,000 ft average lower limit of solifluction deposits and frost rubble of Placer Creek formation.
	Late Spring Draw time	Mountains covered <12,700	Upland distribution and character of Brown Podzolic facies of upper Spring Draw soil.
	Late Harpole Mesa time	−9,000(?)	Estimated.

altitudes to which all four facies of the soil extend, relative to younger like facies, further suggest that the major vegetation zones probably lay at higher altitudes than at any subsquent time and were certainly higher than at present.

During the later part of late Spring Draw time erosion was renewed, probably as a result of increased precipitation acting in phase with a gradual uplift of the region that may have been taking place more or less continuously since late Tertiary or earliest Pleistocene time. The dissection may have begun during the soil-forming optimum, but it became most effective later. The depth of erosion ranged from about 200 feet in and near the mountains to about 90 feet along the Colorado River.

PLACER CREEK TIME

Placer Creek time is that during which the Placer Creek formation was deposited; it comprised two advances of the glaciers, separated by a relatively minor interstadial interval. These glaciations are probably of early Wisconsin age.

EARLY PLACER CREEK TIME

Glaciers of early Placer Creek age probably formed in deep V-shaped gullies eroded in the margins of the broad, shallow cirques that were cut and extensively mantled with talus in Harpole Mesa time. The ice merged on the cirque floors and flowed down-canyon as tongues as much as 8 miles long (pl. 6). The glaciers covered about 30.5 square miles and attained an average lower altitude of about 9,230 feet. At their maximum, they had an estimated volume of about 0.5 cubic miles.

Slopes peripheral to the ice were the scene of widespread solifluction activity which extended to an average lower limit of about 8,000 feet. The thick clayey B horizon of the Spring Draw soils provided an ideal medium for this activity. Adequate water was probably derived from melting snow and thaw of seasonally frozen ground.

Excessive detritus from the glaciers and slopes induced a change in stream regimen from erosion to alluviation, and gravel fills 15 to 30 feet thick were deposited along most valleys.

Eolian activity accompanied and locally outlasted glaciation, as indicated by eolian deposits that are interbedded with, and overlie, the lower member of the Placer Creek formation beneath the upper member.

Average tree line was probably at about 9,500 feet (table 13). Locally it may have extended upward to 10,500 feet, the upper limit of preservation of Spring Draw soils, and elsewhere may have extended downward to altitudes as low as 7,500 feet as a result of intense solifluction Timberline was probably lowered more by the effect of physical processes than by the downslope migration of the vegetation zones. The average lower limit of spruce, now largely on Brown Podzolic soils, probably did not extend much below 8,200 feet, the lower limit of the Brown Forest facies of the Spring Draw soils, at which altitude spruce occurs now in a few places. The Brown soil facies at lower altitudes presumably could not have maintained its character long under a spruce forest. Therefore the altitude range of spruce may have been constricted rather than uniformly lowered. Ponderosa pine and oak, whose average lower limits now lie between 7,500 and 8,000 feet, possibly extended down to about 6,000 feet, the average lower limit of the Brown soil facies of the Spring Draw soils and at which altitude oak is found very locally today. They probably did not extend much farther downslope because such trees are not found on Sierozem soils.

PORCUPINE RANCH TIME

Porcupine Ranch time includes the Porcupine Ranch soil-forming optimum and subsequent erosion prior to the next glaciation. The glaciers of early Placer Creek age probably had disappeared entirely from the La Sal Mountains by the beginning of Porcupine Ranch time. Though the range of facies of the Porcupine Ranch soil is incompletely known (fig. 19), the aspect of its Brown soil and Sierozem facies, as compared with similar facies of better known soils, indicates that the Porcupine Ranch soil probably formed when glaciers were absent. The relatively weak profile suggests that the soil-forming optimum was comparatively short. Slopes were mostly stable, except perhaps in summit areas.

The climate during soil formation is inferred to have been similar to that of today, though possibly somewhat warmer and wetter. Timberline during the warmest part of the interval was probably slightly higher than at present.

Soil development was followed by an interval of erosion, which suggests an increase in precipitation under gradually cooler conditions prior to the next glacial advance. The dissection averaged less than 30 feet in depth and does not appear to have taken place in Castle Valley.

LATE PLACER CREEK TIME

Late Placer Creek time included deposition of the upper member of the Placer Creek formation. Glaciers of late Placer Creek age reoccupied all the early Placer Creek cirques and extended down the same canyons, though not as far as those preceding (pl. 6). The ice extended to an average lower limit of 9,670 feet and covered approximately 30.5 square miles. Its volume is estimated to have been about 1.5 cubic miles, or only about half that of the early Placer Creek glaciers.

Unglaciated slopes were subjected to widespread solifluction of about the same extent and intensity as in early Placer Creek time. Few frost-rubble deposits were formed.

Coincident with glaciation, stream regimen changed from erosion to deposition, and gravel fills, 15 to 20 feet thick, were deposited in valleys. These deposits were not as extensive, however, as those of early Placer Creek time.

The relative order in which depositional processes became inactive during late Placer Creek deglaciation, as determined from the stratigraphic relations of the deposits, was, at any given altitude, glacial deposition, solifluction, coarse alluviation, and frost-rubble formation. At high altitudes, talus continued to form well after the cirques were empty of ice. At low altitudes, eolian deposits, slope-wash mantle, fine-grained alluvium, and locally derived alluvial-fan gravel continued to be deposited well into the subsequent interstadial interval.

Tree line and the distribution of vegetation zones were probably about the same as during early Placer Creek time.

The influence of the Placer Creek glacial environment on the profile of the Spring Draw soil appears to have been remarkably slight, for relict profiles of any given facies show little apparent megascopic difference from profiles buried beneath deposits of early Placer Creek age. Low ground temperatures during glaciation are believed to be responsible.

The question may be raised as to why the Cca horizon of Pedocal facies of the Spring Draw soil was not completely leached during the wet climatic conditions of Placer Creek and later glacial times. Although a positive answer cannot be given, some suggestive evidence is available.

During glaciation certain environmental factors tend to increase the rate of solution of carbonate from a pedocal soil, whereas others tend to decrease the rate and thus to preserve the carbonate. For example, cold water passing through the soil can hold more carbonate in solution than warm water, but the decreased rate of chemical and bacterial activity in a cold environment slows the rate at which carbonate is released into solution. The lowering of conifer vegetation into a pedocal environment during glaciation increases the potential rate at which organic acids are produced in that environment, but the length of the season in which the ground is frozen decreases the time during which such acids may be produced, thus lessening their effectiveness in dissolving carbonate. Longer seasons in which the ground is frozen also lessen the effectiveness of increased precipitation in dissolving carbonate by increasing runoff and decreasing recharge through the soil. It is therefore inferred that the carbonate horizons of pedocal soils are preserved through subsequent glacial climates primarily because the colder temperatures prevailing during glaciation effectively offset any potential increase in solution induced by an increase in precipitation and organic acids in the humus.

LACKEY CREEK TIME

Lackey Creek time followed recession of the glaciers in late Placer Creek time. Eolian activity that probably began in late Placer Creek time appears to have continued well into the early part of Lackey Creek time, for extensive eolian deposits mantle till and solifluction debris of the upper Placer Creek formation, which must have been stagnant for the eolian deposits to be preserved. Slackening of the transporting power of the streams caused a change in the texture of alluvial deposits from gravel to fine-grained sediments. Arroyos were then cut prior to development of the Lackey Creek soil. This succession of events suggests that the climate of the early part of the interglacial interval was dryer and warmer than during recession of the glaciers in late Placer Creek time.

During the Lackey Creek soil-forming optimum most slopes were stable and covered with vegetation. The presence of the Brown Podzolic facies of the soil on many high slopes suggests that the mountains were completely forested (table 13). The major vegetation zones probably lay somewhat lower than during late Spring Draw time, though higher than today. During the early part of the soil-forming optimum, an environment favoring accumulation of calcium carbonate in the soil extended upslope to an altitude of about 9,000 feet (fig. 19). During the latter part, an environment favoring leaching of carbonate extended downslope to about 5,600 feet, inducing the sharply leached boundary between the B and Cca horizons of the Brown Forest and Brown soil facies.

The climate during the soil-forming optimum is believed to have been relatively warmer and wetter than now and to have become increasingly wetter, and gradually cooler, in the latter part of the interval. That temperatures were probably not as warm as during formation of the Spring Draw soils is indicated by the relatively lower range in altitude of facies of the Lackey Creek soil and, in particular, by the lower average altitude of its pedalfer-pedocal boundary (fig. 19).

The relatively strong development of the Lackey Creek soil suggests that the duration of the soil-forming optimum was relatively long. Though not as long as that of the Spring Draw soils, it was probably longer than any younger soil-forming optimum.

The effect of the environment of Lackey Creek time on relict profiles of the Spring Draw soils appears to have been slight. Some pedocal profiles of the Spring Draw soils display composite features, such as secondary carbonate accumulations along structural openings in the B-horizon, that are due to superposition of a later soil-forming environment. In places, such features can be related to the Lackey Creek soil.

In contrast, the Lackey Creek soil effectively masked the Porcupine Ranch soil, except where that soil was buried by the upper member of the Placer Creek formation.

The mountains are presumed to have been completely forested because the strongly developed Lackey soil is now found as high as 11,500 feet and probably extended to the summits, and sandy solifluction debris, rather than frost rubble which today impedes the development of forests, covered the summit uplands. Vegetation zone boundaries were probably much the same as during Spring Draw time, though possibly at slightly lower altitudes.

In the latter part of Lackey Creek time, after the soil-forming optimum, the streams became rejuvenated. Valley floors were dissected to depths of 30 to 50 feet in the lower parts of the region and less at higher altitudes. This erosion was probably the result of a gradual increase in precipitation under increasingly cooler conditions preceding the next glacial interval.

BEAVER BASIN TIME

Beaver Basin time is that in which the Beaver Basin formation was deposited. It comprised two advances of the glaciers, separated by a relatively minor interstadial interval, and is believed to be of late Wisconsin age. At no place in the mountains did the glaciers attain the size or extent of those of preceding glaciations.

EARLY BEAVER BASIN TIME

Glaciers of early Beaver Basin age failed to reoccupy many cirques formed in Placer Creek time, and formed in only the more sheltered parts of many others (pl. 6). The extent of talus on which the Lackey Creek soil is developed in unoccupied cirques suggests that glaciers of early Beaver Basin age were heavily laden with rock debris in their preliminary phases of development. Though most of these eventually became typical valley glaciers, a few rock glaciers were formed. The ice attained an average lower limit of about 10,270 feet and covered approximately 8.7 square miles. It probably had a maximum volume of about 0.3 cubic mile.

Freezing, thawing, and mass-wasting of periglacial slopes resulted in widespread frost-rubble deposits that extend from the summit uplands to an average lower limit at about 8,500 feet. Formation of frost rubble instead of solifluction deposits, which were widespread in Placer Creek time, may be due to two factors. In summit areas, jointed bedrock was more widely exposed than in Placer Creek time, thereby favoring the development of rubble by frost-riving. In other parts of the mountains where slopes were largely covered by till or solifluction mantle the relatively small amount of silt and clay in these deposits and in the Lackey Creek soil on them favored development of rubble through segregation of the coarse fragments by frost-heaving, thawing, and flushing out of the fines, accompained by varying amounts of downslope movement. In Placer Creek time, on the other hand, the thick clayey B horizon of the Spring Draw soils and the silty character of many deposits of the Harpole Mesa formation favored development of solifluction mantle.

The increase in material supplied to the streams from glaciers and slopes caused them to deposit gravel fills, 10 to 30 feet thick. Most of these gravels lie in trenches cut during Lackey Creek time. Locally, however, as in Castle Valley and Spanish Valley, they overlap alluvial deposits of Placer Creek age.

Eolian activity appears to have been widespread, for eolian deposits lie on several of the highest peaks.

Tree line was probably at an average altitude of about 10,000 feet (table 13). In places, it may have extended to 11,500, the upper limit to which the Lackey Creek soil is preserved, and elsewhere it may have been restricted to 8,500 feet, the average lower limit of frost rubble deposits of the upper member of the Beaver Basin formation. The lower limit of spruce is inferred to have ranged between 7,600 feet and 8,400, the respective average lower limits of the Brown Forest facies of the Lackey Creek and Spring Draw soils, to which altitude spruce extends very locally today. Oak and ponderosa pine may have extended as low as 5,600 feet, the average lower limit of the Brown soil facies of the Lackey Creek soil, though today oak extends in only a few places as low as 6,600 feet and ponderosa to 8,400 feet on Brown soils.

PACK CREEK TIME

During Pack Creek time, the glaciers formed in early Beaver Basin time receded to the cirques and probably evacuated most of them, though they may not have disappeared entirely from the mountains. A marked decrease in transporting power of the streams caused an abrupt change in texture of the alluvial deposits from coarse to fine. In places, alluviation virtually ceased, because the Pack Creek soil is found on alluvial deposits of early Beaver Basin age at altitudes as high as 9,500 feet. The streams did not cease to flow, however, for the profile of the soil on flood-plain deposits represents, for the most part, a wet local environment at the time of soil development.

During the soil-forming optimum, a relatively warm, dry, pedocal-forming environment extended upslope to an average altitude of about 7,800 feet (fig. 19). The relatively weakly developed and locally azonal character of the soil suggests, however, that the optimum was relatively short.

Probably most slopes were stable, except perhaps in the higher mountains. Tree line and vegetation zones probably shifted upslope somewhat from their position in early Beaver Basin time.

Rejuvenation of the streams, as a result of increased precipitation in the latter part of the interval before the next glacial advance, induced erosion in the mountains on a relatively minor scale. In the lowlands, however, many valley floors were not dissected.

LATE BEAVER BASIN TIME

Glaciers of late Beaver Basin Age reoccupied nearly all the cirques formed in early Beaver Basin time but failed to attain the volume and extent of early Beaver Basin glaciers, especially in the large compound cirque basins (pl. 6). As a result, a great many relatively small individual masses of ice were developed. They attained an average lower limit of about 10,630 feet, covered approximately 4.4 square miles, and had an estimated volume of only about 0.08 cubic mile.

Periglacial mass-wasting was similar to that of early Beaver Basin time but somewhat more restricted in extent. Eolian activity also appears to have been similar to that of early Beaver Basin time, as was the disposition of tree line and vegetation zones.

Cessation of depositional processes at the close of glaciation was in the same relative order as during the closing phase of glaciation during Placer Creek time.

This succession of events at the close of glaciation suggests that the regional climate was probably dry and cold during recession of the ice but that it became gradually warmer at the beginning of the next interstadial interval.

The effect of the Beaver Basin glacial environment on relict profiles of the Lackey Creek and Spring Draw soils was slight. Soil-forming processes appear to have been practically brought to a standstill by the decrease in temperature during glaciation.

In some parts of the Southern Rocky Mountains, such as the Sawatch and Front Ranges of Colorado, deglaciation during late Beaver Basin time is marked by the development of a small moraine in the upper part of many canyons. This moraine appears to represent either a recessional stand or minor readvance of the ice. In the La Sal Mountains, however, no such moraine was noted.

CASTLE CREEK TIME

Castle Creek time is equivalent to the "altithermal" interval (Antevs, 1948) or "postglacial optimum." It followed a gradual recession of the glaciers formed in late Beaver Basin time. During this interval the ice must have completely disappeared, because the Castle Creek soil is widespread both in the cirques and on upland deposits that were subjected to intensive frost action in late Beaver Basin time.

Eolian silt was deposited on till in the cirques and in the interstices of frost rubble deposits which must have been inactive for the silt to be preserved. Talus cones, on which the Castle Creek soil is formed, lie below many cirque headwalls that were occupied by ice in late Beaver Basin time. The fact that coarse gravel of the upper member of the Beaver Basin formation grades upward into fine-grained alluvium shows that deposition continued after the influence of the glacial environment had ceased.

Although an interval of relatively minor arroyo-cutting locally intervened between deposition of the fine-grained alluvium and development of the Castle Creek soil, this erosion did not approach that which followed soil development. The widespread and readily identifiable Castle Creek soil is therefore the best defined boundary between Pleistocene and Recent deposits in this region.

The Castle Creek soil formed under conditions of relative slope stability. Its character and range in facies suggest a gradual increase in precipitation during the soil-forming optimum, with relatively warm temperatures in the early part and gradually decreasing temperatures in the latter part. During the early part, an environment favoring calcium carbonate accumulation in the profile extended upslope to an average altitude of at least 8,000 feet (fig. 19). During the latter part, an environment favoring leaching of carbonate extended downslope through the range of the Brown Forest and Brown soil facies to an average altitude of 5,400 feet.

That the Castle Creek soil-forming optimum was not as warm as the Lackey Creek or Spring Draw soil-forming optima is shown by the relatively lower altitude range of all facies of the Castle Creek soil and, in particular, by the lower average altitude of its pedalfer-pedocal boundary (fig. 19). From similar reasoning, the Castle Creek soil-forming optimum is inferred to have been warmer than at any subsequent time.

The relatively moderate development of the Castle Creek soil suggests that the soil-forming optimum was shorter than either the Lackey Creek or Spring Draw soil-forming optimum but that it was longer than either the Porcupine Ranch or the Pack Creek soil-forming optimum and also longer than any subsequent soil-forming optimum.

In general, the effect of the environment of the Castle Creek interval on relict profiles of the Spring Draw or Lackey Creek soils was negligible, though locally those older soils are modified by superposition of the Castle Creek soil. In contrast, the effect of the Castle Creek environment on the Pack Creek soil was such as to mask effectively its original character except where it was buried beneath the upper member of the Beaver Basin formation.

The presence of the Brown Podzolic facies of the Castle Creek soil on many of the highest slopes indicates that the mountains were prevented from being completely forested (table 13) only by the widespread deposits of block rubble formed in Beaver Basin time. The vegetation zones probably lay somewhat lower than during Lackey Creek or late Spring Draw times but were probably higher than at any subsequent time including the present. The average lower limit of spruce is inferred to have been at an altitude of about 8,000 feet, which is the average lower limit of the Brown Podzolic facies of the Castle Creek soil. Oak and ponderosa pine may have extended to about the average lower limit of the Brown Forest facies at 7,200 feet.

Toward the end of Castle Creek time, the streams were rejuvenated and an episode of erosion took place under conditions of gradually increasing precipitation and gradually decreasing temperature preceding the next glacial advance. Depth of dissection averaged 15 to 30 feet in the lower valleys and less in the mountains.

GOLD BASIN TIME

Gold Basin time is that in which the Gold Basin formation was deposited, and is of Recent age. It included two minor glacial advances, separated by a brief interstadial interval. Together, the two advances represent the Little Ice Age of Matthes (1939, 1940).

EARLY GOLD BASIN TIME

Early Gold Basin time is that in which the lower member of the Gold Basin formation was deposited. Small bodies of ice formed in about three-fourths of the cirques that had been occupied in late Beaver Basin time (pl. 6). Rock glaciers formed in about half of these cirques; small glaciers were confined within the others. The ice attained an average lower limit of 11,100 feet and covered approximately 1.5 square miles. Its volume is estimated to have been about 0.02 cubic mile.

The rock glaciers are believed to have formed as the result of inseepage and freezing of snow melt water in thick talus cones which had formed in the cirques at the close of Beaver Basin glaciation. In some places forward movement of the talus may have been started by solifluction; in others, movement resulted from flow of interstitial ice, which differed from glacial ice in having formed by freezing of interstitial water rather than through recrystallization of snow.

On periglacial slopes, freezing and thawing of water derived largely from melting snow reactivated parts of many Beaver Basin frost-rubble deposits, so that new forms developed within the old to an average lower altitude of about 11,000 feet. All varieties of frost rubble are represented.

In the valleys, an increase in stream load from outwash and mass-wasting caused stream regimen to change from erosion to deposition. The transporting power of the streams, however, even during the glacial maximum was insufficient to move coarse debris throughout their length, as during previous glaciations. Coarse alluvium was deposited only near the ice or close to local sources at the foot of slopes. In contrast, fine alluvium was widely distributed, especially in the lower valleys where it not only filled channels cut during Castle Creek time but overlapped the surface of late Beaver Basin terraces. The earliest evidence of inhabitation of the region by man is provided by hearth sites and artifacts of a prepottery stone culture in these deposits. Carbon 14 analysis of charcoal from the hearth sites indicates an age of 2,800 $\pm$200 years, or about 900 B.C.

In places, the alluvium contains a number of buried humus zones. Most of these represent merely brief intervals of local nondeposition and associated flood-plain vegetation. One zone, however, is extremely persistent and suggests that early Gold Basin time may include two episodes of alluviation, possibly associated with two pulsations of the glaciers, separated by a brief but widespread interval of nondeposition. Two end moraines are associated with the glaciation correlated with the early Gold Basin in some parts of the Rocky Mountains, for example, in Rocky Mountain National Park.

Extensive eolian activity during early Gold Basin time provided an abundance of fine-grained material to the streams, choking them in some places. It was probably in large measure responsible for the amount of alluviation of fine-grained material.

The climate of early Gold Basin time, though cold enough for glaciation, was probably only a few degrees colder than at present. Precipitation is inferred to have been considerably less than during previous glaciations but somewhat greater than at present. Tree line was probably about 11,000 feet, or only slightly lower than at present (table 13). As a whole, this glacial episode must have been relatively brief, perhaps on the order of 1,000 years.

SPANISH VALLEY TIME

Spanish Valley time followed stagnation and melting of the glaciers of early Gold Basin age. It was characterized by widespread slope stability and by the formation of the Spanish Valley soil. The presence of this soil in the cirque heads on till and talus of early Gold Basin age indicates that the glaciers of early Gold Basin age had disappeared entirely. The distribution of the soil facies with altitude suggests that an environment favoring carbonate accumulation in the soil extended upslope to an average altitude of about 7,000 feet (fig. 19), or about 600 feet higher than in the soil on modern flood plains. From this it may be inferred that the climate was slightly warmer than at present. Precipitation may also have been somewhat greater. The very weak development of the Spanish Valley soil suggests that the soil-forming optimum was relatively short.

The distribution of dead unburned trees above present timberline suggests that tree line may have locally extended as high as 11,500 feet (table 13), an altitude which coincides approximately with the lower limit of widespread inactive frost rubble of Beaver Basin and early Gold Basin age.

In the latter part of Spanish Valley time, rejuvenated streams cut arroyos between 10 and 20 feet deep along most of the valleys in the lower part of the area.

LATE GOLD BASIN TIME

Late Gold Basin time is that in which the upper member of the Gold Basin formation was deposited. It includes the last major glacial episode for which there is widespread stratigraphic evidence. The last important pulsation of this episode may have culminated prior to 1860, the approximate date of the last glacial maximum in other parts of the Rocky Mountains, for no glaciers have been reported in the La Sal Mountains since settlement of the region.

The climatic change that brought on glaciation was relatively slight, for only 7 of the 32 cirques occupied by early Gold Basin glaciers were reoccupied in late Gold Basin time (pl. 6). Rock glaciers formed in 6 of these. The ice extended to an average lower limit of about 11,130 feet. It covered only about 0.2 square mile and had an estimated volume of only 0.002 cubic mile.

Frost action on upland slopes reactivated small areas of frost rubble within older deposits of early Gold Basin age. Most of those reactivated are stagnant at present.

A sufficiently increased load was supplied to the streams to induce a change in regimen from erosion to deposition, especially in the lower parts of the major valleys. The alluvium is mostly fine grained and represents material of local origin blown or washed into the streams at low altitudes. Mass-wasting and glaciation at high altitudes apparently contributed only small amounts of debris, most of which was deposited near its source.

The eolian and slope-wash activity, though influencing stream regimen at low altitudes, was greatly restricted in extent as compared with that of previous times. Both eolian and alluvial deposits contain evidence of human occupation exhibiting several stages of pottery culture.

Differences from the present distribution of vegetation were not great. Tree line may have been at about 11,300 feet, or slightly lower than at present (table 13).

PRESENT TIME

Since the beginning of the 20th century, geologic events in the region have tended to duplicate those at the beginning of earlier interglacial intervals. Rock glaciers are inactive and movements of the mantle related to frost action are negligible. The development of talus is waning and is restricted largely to the cirques. Eolian activity is restricted to small areas in the major valleys or on the lower plateaus. Deposition of fine alluvium has practically ceased and an interval of arroyo-cutting has produced narrow, deep gullies. The unusual depth of arroyo-cutting may locally be due to the influence of man. This influence, however, is of dual character, for, although overgrazing and removal of timber may locally have increased the depth of gullying, removal of irrigation water from the streams has tended to decrease erosion and deposition on the flood plains to the extent that very thin azonal soils are beginning to make their appearance locally. Tree line is at an average altitude of 11,400 feet and appears to be advancing upward. The geologic evidence on the whole suggests that since the glaciers disappeared the climate has tended to become increasingly warm and dry, but whether or not this is a long-term trend cannot be ascertained.

STRATIGRAPHIC SECTIONS OF SOILS

In the following pages, 46 stratigraphic sections of soil profiles, which have been referred to in preceding parts of this report, are described in detail. The form of these descriptions follows as closely as possible that suggested by the U.S. Department of Agriculture Soil Survey Manual (1951), though some differences have been necessitated in order to adequately describe buried soils as they occur stratigraphically between overlying and underlying deposits. An effort has been made to distinguish clearly between rock units of geologic formations, such as till, gravel, eolian sand, or other deposit, and the soil profiles formed on these deposits.

Geologic names of soils and rock formations are defined in the preceding parts of this report. The descriptions are arranged according to the stratigraphic succession and geologic age of the soils, beginning with the oldest (Spring Draw soils) and progressing toward the youngest (Spanish Valley soil). Typical profiles of each facies (or great soil group) in which each named soil is developed are described.

1. *Spring Draw soils, Brown Podzolic facies*

[Relict profile on dioritic till of the upper member of the Harpole Mesa formation. Measured at altitude of 9,700 feet in wall of irrigation ditch at head of Twomile Creek (NW¼NW¼ sec. 29, T. 27 S., R. 25 E.). The vegetation is mainly spruce and aspen]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Superposed soil of unknown stratigraphic affinity.	0–4	A	Leaves and decayed litter. Gradual boundary.
	4–12	A_1	Very dark gray-brown (7.5*YR* 3/2) stony sandy loam. Structure: weak fine crumb. Consistence: slightly sticky, slightly plastic, friable, soft. Reaction: medium-acid. Gradual boundary.
Upper Spring Draw soil on till of upper member of Harpole Mesa formation.	12–96	B	Reddish-brown (5*YR* 5/4) stony silty clay loam. Structure: coarse angular blocky. Consistence: sticky, plastic, firm, hard. Reaction: very strongly acid. Kaolinized feldspar flecks throughout. Many diorite cobbles disintegrated throughout or have ½- to 1-inch weathered rind. Most are stained yellowish brown. A few are hard and unweathered. Diffuse boundary.
	96+	C	Parent till. Yellowish-brown (5*YR* 5/4) stony sandy clay loam. Structureless. Consistence: nonplastic, friable, compact. Reaction: strongly acid. Rock fragments weathered as in B horizon above.

2. *Spring Draw soils, Brown Podzolic facies*

[Buried profile on dioritic till of middle(?) member of Harpole Mesa formation. Measured at altitude of 10,500 feet on west side of Geyser Pass (NW¼NW¼ sec. 1, T. 27 S., R. 24 E.). The vegetation is mainly spruce-fir climax with meadow parks. At this locality, till of the upper member of the Harpole Mesa formation, on which the upper Spring Draw soil is developed, overlies an older till, possibly the middle member of the formation, on which the middle(?) Spring Draw soil is preserved in a buried condition. The upper part of the upper Spring Draw soil has been considerably truncated and altered by later frost action and other periglacial processes, with the result that only the lower part of the profile appears intact. The underlying profile is, however, almost fully preserved. The thickness of its B horizon is more probably representative of the original thickness of the Brown Podzolic facies of the lower and middle Spring Draw soils than that of the more commonly observed truncated relict profiles]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Younger soil (probably the Castle Creek soil) on eolian sand and silt.	0–0.5	A	Grass and spruce litter.
	0.5–2	A_1	Dark-brown (10*YR* 4/3) humic eolian fine sand and silt. Structure: very fine granular. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: medium-acid. Gradual boundary.
	2–9	B	Pink (7.5*YR* 7/4) eolian fine sand and silt. Structure: very fine granular. Consistence: nonsticky, nonplastic, friable, soft. Reaction: strongly acid. Gradual boundary.
	9–25	C	Light-brown (7.5*YR* 6/6) eolian fine sand and silt that fills interstices between closely packed subround to subangular fragments of diorite in a buried rubble sheet. A few fragments are rotted throughout; a few are crumbly. Structure: very fine granular. Consistence: slightly sticky, slightly plastic, friable, soft. Reaction: very strongly acid. Clear boundary.
Younger soil of unknown stratigraphic affinities on fine sand and silt wash.	25–27	A	Dark-brown (7.5*YR* 4/2) humic fine sand and silt as lenticular streaks which formed at base of rubble sheet prior to accumulation of eolian sand and silt. Structure: very fine granular. Consistence: friable, soft. Reaction: strongly acid. Disconformity.

2. *Spring Draw soils, Brown Podzolic facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Upper Spring Draw soil on till of upper member of Harpole Mesa formation.	27–32	B	Reddish-brown (5*YR* 5/4) sandy clay till with subangular to angular fragments of diorite. Many rotted or deeply stained. Structure: strong medium-platy. Consistence: sticky, plastic, firm, hard. Reaction: very strongly acid. Distinct medium mottling (7.5*YR* 5/6) represents an alteration of original profile. Diffuse boundary.
	32–41	B_2	Strong-brown (7.5*YR* 5/6) sandy clay till as above. Structure: moderate medium-platy. Consistence: sticky, plastic, firm, hard, compact. Reaction: very strongly acid. Diffuse boundary.
	41–53	B_3	Brown (7.5*YR* 5/4) sandy clay till as above. Structure: moderate medium-platy. Consistence: sticky, plastic, firm, hard, compact. Reaction: very strongly acid. Diffuse boundary.
	53–71	C	Reddish-brown (5*YR* 5/4) sandy clay till as above. Reaction: very strongly acid. Color due to material incorporated from till sheet beneath. Diffuse boundary.
	71–96	C	Light reddish-brown (5*YR* 6/4) sandy clay till as above. Reaction: very strongly acid. Disconformity.
Middle(?) Spring Draw soil on till of middle member(?) of Harpole Mesa formation.	96–124	B	Yellowish-red (5*YR* 5/6) mottled reddish-brown (5*YR* 4/4) clayey till. Contains few cobbles of diorite, mostly rotted. Structure: moderate medium-platy. Consistence: very sticky, very plastic, firm, very hard and compact. Reaction: extremely acid. Diffuse boundary.

2. *Spring Draw soils, Brown Podzolic facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Middle(?) Spring Draw soil on till of middle member(?) of Harpole Mesa formation—Con.	124–216	B	Yellowish-red (5*YR* 4/6) mottled reddish-yellow (5*YR* 6/6) clayey till with a few fragments of diorite, mostly rotted or deeply stained. Structure: weak medium-platy to very coarse angular blocky. Consistence: very sticky, very plastic, firm, very hard and compact. Reaction: extremely acid.
	216–300		Slope covered with landslide debris. Contact of till and Mancos shale at depth of approximately 300 inches. No fresh till observed.

3. *Spring Draw soils, Brown Podzolic facies*

[Relict profile on till of Harpole Mesa formation composed mostly of sandstone. Measured at altitude of about 9,400 feet, in wall of irrigation ditch on bench south of Warner Ranger Station (SE¼NE¼ sec. 28, T. 26 S., R. 24 E.). The vegetation is mainly aspen and meadow subclimax]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Superposed soil of unknown stratigraphic affinity.	0–4	A	Litter
	4–16	A_1	Dark-gray (5*YR* 4/1) stony, sandy loam. Structure: weak fine crumb platy in lower part. Consistence: nonsticky, nonplastic, friable, soft. Reaction: medium-acid. Gradual boundary.
Upper Spring Draw soil on till of upper member of Harpole Mesa formation.	16–70	B	Weak-red (10*R* 4/3) stony, sandy loam. Structure: medium granular grading down into moderate coarse subangular blocky. Consistence: sticky, slightly plastic, firm, hard. Reaction: strongly acid. Rock fragments all of sandstone. Many are stained to depths as much as 1½ inches. Some are crumbly; some are fresh. Diffuse boundary.
	70+	C	Pale-red (10*YR* 6/2) stony, sandy loam. Structureless. Consistence: nonsticky, nonplastic, compact, firm, hard. Reaction: medium-acid. Fragments all of sandstone. Many stained as above. Some are crumbly; some are fresh.

4. *Spring Draw soils, Brown Podzolic facies*

[Relict profile on till of Harpole Mesa formation composed mostly of Mancos shale. Measured at altitude of about 9,400 feet on east rim of Bald Mesa, on slope above irrigation ditch (SW¼SE¼ sec. 20, T. 26 S., R. 24 E.). Although the larger rock fragments in the till are of diorite and sandstone, the matrix appears to be almost wholly derived from the underlying Mancos shale. The vegetation is a sagebrush association]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Superposed soil of unknown stratigraphic affinity.	0–2	A	Litter.
	2–12	A_1	Dark-reddish-brown (5*YR* 3/2) stony silt loam. Structure: moderate fine crumb. Consistence: slightly sticky, slightly plastic, friable, soft. Reaction: medium-acid. Gradual boundary.
Composite Spring Draw soil on till of middle or upper member of Harpole Mesa formation.	12–72+	B	Yellowish-red (5*YR* 5/6) stony, clay till; locally mottled reddish brown (5*YR* 4/4). Structure: strong medium angular blocky in upper part, becomes weaker downward. Consistence: sticky, plastic, firm, very hard. Reaction: medium-acid. Fragments of diorite and sandstone are not abundant and are deeply disintegrated or stained. Lower part of section is poorly exposed and fresh till was not observed.

5. *Spring Draw soils, Brown Podzolic facies*

[Poorly drained buried profile on till of upper member of Harpole Mesa formation. Measured in pit and auger excavation at altitude of about 9,300 feet in southeast part of Boren Mesa (NE¼NE¼ sec. 4, T. 27 S., R. 24 E.). The Spring Draw soil is overlain by silty deposits of possible eolian origin on which the Brown Podzolic facies of the Lackey Creek soil is developed. The vegetation is grass]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Lackey Creek soil developed on eolian(?) deposits.	0–2	A	Grass litter.
	2–6	A_1	Dark-gray (10*YR* 4/1) stony sandy silt loam. Structure: weak fine crumb. Consistence: nonsticky, nonplastic, very friable, slightly hard. Reaction: slightly acid. Diffuse boundary.
	6–14	A_2	Light-gray (10*YR* 7/2) fine sandy silt loam. Structure: weak fine angular blocky. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: medium-acid

5. *Spring Draw soils, Brown Podzolic facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Lackey Creek soil developed on eolian(?) deposits—Continued	14–38	B	Yellowish-brown (10*YR* 5/6) fine sandy silt loam. Structureless. Consistence: nonsticky, slightly plastic, friable, slightly hard.
Upper Spring Draw soil on till of upper member of Harpole Mesa formation.	38–54	A_1	Very dark gray (7.5*YR* 3/0) muck. Structure: moderate-platy to fine angular blocky. Consistence: sticky, plastic, friable, hard. Reaction: very strongly acid. Gradual boundary.
	54–58	A_2	Light-gray (10*YR* 7/2) stony sandy clay till, lenticular. Structureless. Consistence: nonsticky, nonplastic, friable, hard. Reaction: strongly acid. Gradual boundary.
	58–78	B_2	Brown (7.5*YR* 5/4) stony sandy clay till. Structure: weak angular blocky. Consistence: sticky, plastic, firm, hard. Reaction: very strongly acid. Diffuse boundary.
	78–104	B_3	Yellowish-red (5*YR* 5/6) stony sandy clay till. Structure: weak coarse angular blocky. Consistence: sticky, plastic, firm, hard. Reaction: very strongly acid. Diffuse boundary.
	104–112+		Olive-gray (5*Y* 5/2) sandy clay till. Structureless. Consistence: sticky, plastic, firm, very hard. Reaction: strongly acid. Rock fragments are of diorite, sandstone, and shale. Many are deeply stained or disintegrated.

6. *Spring Draw soils, Brown Forest facies*

[Relict profile developed on outwash gravel of the Harpole Mesa formation composed of a mixture of diorite and sandstone. Measured at altitude of 8,400 feet on south side of Beaver Creek, half a mile above the crossing of the county road (SE¼SW¼ sec. 4, T. 26 S., R. 25. E.). The vegetation is sagebrush and grass]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Superposed modern soil.	0–2	A_0	Litter.
	2–8	A_1	Dark-gray (5*YR* 4/1) fine sandy loam. Structure: moderate medium crumb. Consistence: nonsticky, nonplastic, very friable, slightly hard. Reaction: slightly acid. Gradual boundary.
Upper Spring Draw soil on alluvial gravel of upper member of Harpole Mesa formation.	8–44	B	Reddish-brown (2.5*YR* 5/4) arkosic sandy gravel. Clay concentrated along structure planes and on undersides of pebbles. Structure: weak medium blocky. Consistence: nonsticky, slightly plastic, friable, slightly hard. Reaction: slightly acid. Diffuse boundary.
	44–84	Cca	Light-reddish-brown (5*YR* 6/4) arkosic sandy gravel. A thin film of calcium carbonate coats pebbles and root holes. Coating is thickest on undersides of pebbles. Structureless. Consistence: nonsticky, nonplastic, firm, hard. Reaction: moderately alkaline.
	84–100+		Parent sandy gravel not observed.

7. *Spring Draw soils, Brown Forest facies*

[Relict profile on till of Harpole Mesa formation composed mainly of sandstone. Measured at altitude of 9,000 feet on north side of Bald Mesa along a gully that cuts through till of Harpole Mesa formation into underlying Mancos shale (SE¼NW¼ sec. 20, T. 26 S., R. 24 E.) (fig.20). The vegetation is sagebrush association]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Younger superposed soil of unknown stratigraphic affinity.	0–1	A	Grass and leaf litter.
	1–8	A_1	Dark reddish-brown (5*YR* 3/2) pebbly silt loam. Structure: moderate fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: slightly acid. Gradual boundary.

7. *Spring Draw soils, Brown Forest facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Composite Spring Draw soil on till of lower or middle member of Harpole Mesa formation.	8–38	B	Red (2.5*YR* 5/6) cobbly to channery sandy till. Structure: moderate medium angular blocky becoming weaker downward. Consistence: slightly sticky, slightly plastic, friable, hard. Reaction: slightly acid. Gradual boundary.
	38–86	Cca	Reddish-brown (2.5*YR* 5/4) cobbly to channery sandy clay till. Structureless, except for a few widely separated joints. Consistence: sticky, plastic, firm, hard. Reaction: mildly alkaline. Films and thin coatings of calcium carbonate coat joints and undersides of pebbles. Sharp unconformity.
	86–180		Shattered Mancos shale with calcium carbonate films concentrated along joint planes and other permeable zones.

8. *Spring Draw soils, Brown soil facies*

[Relict profile on till of the Harpole Mesa formation composed of diorite and sandstone. Measured at altitude of 7,800 feet on till of Harpole Mesa formation along a ditch leading west across central part of Wilson Mesa (NW¼SW¼ sec. 13, T. 26 S., R. 23 E.) (fig. 21). The vegetation is scrub oak and sagebrush]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Younger superposed soil of unknown stratigraphic affinity.	0–1	A	Litter.
	1–7	B	Brown (7.5*YR* 5/2) stony sandy loan. Structure: moderate fine granular thin platy in lower part. Consistence: nonsticky, nonplastic, very friable, slightly hard. Reaction: slightly acid. Some rock fragments rotted, many deeply stained. Clear boundary.
Upper Spring Draw soil on till of lower or middle member of Harpole Mesa formation.	7–33	B	Reddish-brown (2.5*YR* 5/4) stony sandy clay till, containing many grains of partly decomposed feldspar. Structure: strong fine columnar. Consistence: sticky, plastic, friable, hard. Reaction: slightly acid. Numerous krotovinas. Abrupt irregular contact.

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8. *Spring Draw soils, Brown soil facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Upper Spring Draw soil on till of lower or middle member of Harpole Mesa formation—Continued	33–100	Cca	White (5*YR* 8/1) stony sandy loam. Structure: medium platy grading down into coarsely jointed massive till. Consistence: slightly sticky, slightly plastic, friable, slightly hard. Reaction: strongly alkaline. Matrix strongly impregnated with calcium carbonate. Carbonate coats rock fragments and is concentrated along joint planes. Cores of joint blocks are only weakly calcified and are reddish brown (5*YR* 5/4), especially in lower part. Numerous krotovinas of B horizon with powdery calcium carbonate coating along walls, and many root tubules and insect borings lined or filled with concentric layers of calcium carbonate. Some rock fragments are deeply disintegrated, and others are deeply stained. Sharp disconformity.
	100+		Bedrock: shale member of Morrison formation with calcium carbonate concentrations along bedding and joint planes.

A section of a buried profile is given in the description of the type locality of the Harpole Mesa formation on page 26.

9. *Spring Draw soils, Sierozem facies*

[Relict profile on dioritic outwash gravel of lower member of Harpole Mesa formation. Measured at altitude of about 5,600 feet on east flank of Johnsons-Up-On-Top, northeast of Spanish Valley (SW¼NE¼ sec. 31, T. 26 S., R. 23 E.). The vegetation is sagebrush and grass]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Younger superposed soil of unknown stratigraphic affinity.	0–1	A	Litter, cobbles coated with partly deteriorated desert varnish, loose sand, and caliche fragments.
	1–6	Bca	Light reddish-brown (5*YR* 6/4) partly leached gravelly sandy loam, mottled pinkish white (5*YR* 8/2). Numerous caliche fragments. Structure: weak subangular blocky. Consistence: slightly sticky, slightly plastic, friable, slightly hard. Reaction: moderately alkaline. Abrupt boundary.

9. *Spring Draw soils, Sierozem facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Composite Spring Draw soil on alluvial gravel of lower member of Harpole Mesa formation.	6–36	Bca	Pink (5*YR* 7/3) gravelly to cobbly sandy loam. Numerous caliche fragments leached away from gravel and broken. Structureless. Consistence: sticky, plastic, firm hard. Reaction: strongly alkaline. Gradual boundary.
	36–180	Cca	White (5*YR* 8/1) sand and cobble gravel. Gravel heavily coated and matrix weakly cemented with calcium carbonate. Structureless. Consistence: nonsticky, nonplastic, firm, hard. Reaction: very strongly alkaline. Calcareous coating and cementation less concentrated in lower part. Diffuse boundary.
	180+	C	Very pale brown (10*YR* 7/3) sand and cobble gravel; calcareous concentrations along streaks and lenses. Crudely bedded. Gravel composed of diorite and sandstone. Deposit rests disconformably on sandstone bedrock.

10. *Porcupine Ranch soil, Brown soil facies*

[Buried profile on dioritic alluvial gravel of lower member of Placer Creek formation. Measured at altitude of about 6,100 feet at type locality of soil near Porcupine Ranch on Placer Creek (SW¼SW¼ sec. 36, T. 25 S., R. 23 E.). Porcupine Ranch soil is overlain disconformably by outwash of upper member of Placer Creek formation on which Lackey Creek soil is developed (fig. 25). The vegetation is a sagebrush association]

Soil and associated rock unit	Depth (inches)	Horizon	Description
	0–2	A	Dark-brown (7.5*YR* 4/2) humic fine sand and silt. Structure: weak fine platy. Consistence: nonsticky nonplastic, very friable, soft. Reaction: neutral. Clear boundary.
Lackey Creek soil on alluvial gravel of upper member of Placer Creek formation.	2–32	B	Reddish-brown (5*YR* 4/3) gravelly fine sandy loam. Structure: moderate medium subangular blocky. Consistence: slightly sticky, slightly plastic, friable, hard. Reaction: slightly acid. Clear boundary.

10. *Porcupine Ranch soil, Brown soil facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Lackey Creek soil on alluvial gravel of upper member of Placer Creek formation—Continued	32–96	Cca	Very pale brown (10*YR* 7/4) sand and gravel, crudely bedded. Structure: strong thin platy. Consistence: nonsticky, nonplastic, friable, hard. Reaction: moderately to strongly alkaline. Gravel coated with carbonate. Weakly cemented in upper part. Diffuse boundry.
	96–134	C	Light - yellowish - brown (10*YR* 6/4) sand and gravel, crudely bedded, friable. Reaction: mildly alkaline to neutral. Disconformity.
Porcupine Ranch soil on alluvial gravel of lower member of Placer Creek formation.	134–148	B	Reddish-brown (5*YR* 5/4) leached sandy clay loam. Structure: weak angular blocky. Consistence: slightly sticky, slightly plastic, friable, hard. Reaction: slightly acid. Small clots of unleached calcareous material in lower part. Abrupt irregular boundary.
	148–154	Cca	Pink (7.5*YR* 7/4) calcareous sandy loam. Structureless. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: moderately alkaline. Contains partly leached root casts and krotovinas derived from *B* horizon. Gradual boundary.
	154–164	Cca	Light-brown (7.5*YR* 6/4) bouldery gravel composed of diorite and sandstone in calcareous sandy to silty matrix. Structure: crudely bedded, poorly sorted. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: moderately alkaline. Calcareous streaks and thin coatings on bottoms of cobbles extend to depth of 2 to 3 feet. Diffuse boundary.

10. *Porcupine Ranch soil, Brown soil facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Porcupine Ranch soil on alluvial gravel of lower member Placer Creek formation—Continued	164–274+	C	Sand and boulder gravel, crudely bedded, friable, soft. Reaction: mildly alkaline. Some secondary carbonate coatings in certain lenses.

11. *Porcupine Ranch soil, Sierozem facies*

[Buried profile on eolian sand of lower member of Placer Creek formation. Measured at altitude of about 4,500 feet, in wall of one of the larger draws dissecting a large alluvial fan about 2 miles south of Moab in Spanish Valley (NE¼SW¼ sec. 17, T. 26 S., R. 22 E.). It represents the most nearly complete profile that was found in the area of the fan. Others are similar but truncated to varying degrees. The Porcupine Ranch soil is overlain by alluvial-fan gravel and eolian sand of the upper member of the Placer Creek formation on which the Sierozem facies of the Lackey Creek soil is developed. Vegetation is sagebrush]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Eolian sand, upper member of Gold Basin formation.	0–12		Sand, loose, crossbedded, active. Abrupt boundary.
	12–14		Angular gravel veneer.
Lackey Creek soil on eolian sand of upper member of Placer Creek formation.	14–36	Bca	Reddish-brown (2.5*YR* 5/4) fine sand and silt. Structureless. Consistence: very friable, soft. Reaction: Moderately alkaline. Abrupt boundary.
	36–84	Cca	Pink (2.5*YR* 6/4 mottled 7/4) fine sand and silt. Structure: moderate coarse columnar. Consistence: nonplastic, friable, hard. Reaction: strongly alkaline. Gradual contact.
	84–110	Cca	Light-reddish-brown (2.5*YR* 6/4) fine sand and subangular gravel, composed of sandstone, crudely bedded. Consistence: friable, slightly hard. Reaction: mildly alkaline. Fragments thinly coated with carbonate along streaks. Diffuse boundary.
	110–230	C	Reddish-brown (2.5*YR* 5/4) sand and angular gravel as above. Neutral to mildly alkaline. Sharp disconformity.

11. *Porcupine Ranch soil, Sierozem facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Porcupine Ranch soil on eolian sand of lower member of Placer Creek formation.	230–236	Bca	Red (2.5*YR* 4/6) sand and silt with a few small pebbles. Structureless. Consistence: very friable, hard. Reaction: moderately alkaline. Secondary carbonate along fractures. Gradual boundary.
	236–266	Cca	Pink (2.5*YR* 6/4 mottled 7/4) fine sand and silt. Structure: weak coarse columnar. Consistence: friable, hard. Reaction: moderately alkaline. Diffuse boundary.
	266–314	C	Reddish-brown (2.5*YR* 5/4) fine sand and silt. Structureless. Consistence: very friable, slightly hard. Reaction: mildly alkaline to neutral. Gradual contact.
	314–350	C	Reddish-brown (2.5*YR* 5/4) sand and angular gravel, composed of sandstone. Crudely bedded, very friable, slightly hard.

12. *Lackey Creek soil, Brown Podzolic facies*

[Buried profile on dioritic till of lower member of Placer Creek formation. Measured at altitude of about 10,700 feet on lateral moraine on north side of canyon of Beaver Creek below hanging valley just east of Beaver Basin (NE¼SE¼ sec. 13, T. 26 S., R. 24 E.). The Lackey Creek soil is overlain by frost rubble whose interstices are filled by eolian sand and silt of the Beaver Basin formation on which the Castle Creek soil is developed. Vegetation is spruce and meadow]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on eolian silt that fills interstices of frost rubble of Beaver Basin formation.	0–4	A	Dark-brown (7.5*YR* 4/2) humic fine sandy silt loam filling interstices between large rock fragments. Structure: very fine granular. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: medium-acid. Clear boundary.
	4–8	B	Light-brown (7.5*YR* 6/4) fine sandy silt loam filling interstices between closely spaced, large rock fragments. Structure: very fine granular. Consistence: nonsticky, nonplastic, friable, soft. Reaction: medium-acid. Diffuse boundary.

12. *Lackey Creek soil, Brown Podzolic facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on eolian silt that fills interstices of frost rubble of Beaver Basin formation—Con.	8–17	C	Pinkish-gray (7.5*YR* 7/2) fine sand and silt filling interstices between closely spaced, large rock fragments. Structure: massive to vermicular with many small root holes. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: strongly acid. Diffuse boundary.
	17–26	C	Large, closely spaced, angular to subangular rock fragments, with many open voids forming a "permeable zone." Some light-brown (7.5*YR* 6/4) silt filling. Reaction: strongly acid. Clear boundary.
Lackey Creek soil on till of lower member of Placer Creek formation.	26–48	B	Strong-brown (7.5*YR* 5/6) very stony sandy till, with closely spaced, large, angular to subangular rock fragments. Structureless. Consistence: nonsticky, nonplastic, friable, hard. Reaction: very strongly acid. Diffuse boundary.
	48–60	C	Pink (7.5*YR* 7/4) very stony sandy till, with closely spaced, angular to subangular rock fragments. Structureless. Consistence: friable, slightly hard. Reaction: very strongly acid.

Compare this profile with that on a genetically different deposit in section 13 and with that on a similar deposit at lower altitude in section 14.

13. *Lackey Creek soil, Brown Podzolic facies*

[Buried profile on dioritic solifluction mantle of Placer Creek formation. Measured at altitude of about 10,800 feet about half a mile southeast of head of Schuman Gulch on ridge between Miners Basin and Wet Fork (SE¼NE¼ sec. 22, T. 26 S., R. 24 E.). The Lackey Creek soil is overlain by frost rubble of Beaver Basin formation, whose interstices are filled with eolain silt on which Castle Creek soil is developed. The vegetation is grass]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on eolian silt that fills interstices of frost rubble of Beaver Basin formation.	0–1	A	Light-brownish-gray (10*YR* 6/2) humic stony silty sandy loam. Structure: weak fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: medium-acid. Clear boundary.

13. *Lackey Creek soil, Brown Podzolic facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on eolian silt that fills interstices of frost rubble of Beaver Basin formation—Continued	1–8	B	Brown (7.5*YR* 5/4) sandy silt loam filling interstices between large rock fragments. Structure: weak fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: medium-acid. Clear boundary.
	8–14		Zone of rock fragments with very little fine material in voids. Clear boundary.
Lackey Creek soil on solifluction mantle of Placer Creek formation.	14–30	B_2	Yellowish-red (5*YR* 4/6) coarse to medium sand, silt, and angular gravel, composed of disintegrated feldspar, filling interstices between large, stained, angular rock fragments. Structureless: Consistence: friable, slightly hard. Reaction: strongly acid. Diffuse boundary.
	30–46	B_3	Brownish-yellow (10*YR* 6/6) coarse to medium sand, silt, and small rock fragments, in interstices between large, stained, closely spaced rock fragments. Structureless. Consistence: friable, slightly hard. Reaction: strongly acid. Diffuse boundary.
	46–60	C	Very pale brown (10*YR* 7/4) coarse to medium sand, silt, and small rock fragments, in interstices between large, very closely spaced, tightly wedged rock fragments that grade downward into fractured bedrock. Structureless. Consistence: friable Reaction: medium-acid.

14. *Lackey Creek soil, Brown Podzolic facies*

[Buried profile on dioritic till of upper member of the Placer Creek formation. Measured at altitude of about 9, 500 feet, in a road cut in the terminal moraine at type locality of upper member of Placer Creek formation in the canyon of Placer Creek (NW¼SE¼ sec. 15, T. 26 S., R. 24 E.). The Lackey Creek soil is overlain by eolian sand and colluvium of the Beaver Basin formation on which the Castle Creek soil is developed. The vegetation is aspen and meadow]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on eolian silt of Beaver Basin formation.	0–9	A	Very dark brown (10*YR* 2/2) humic silty sandy loam with angular to subangular rock fragments. Structure: very fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: slightly acid. Gradual boundary.
	9–36	B, C	Very pale brown (10*YR* 7/4) fine sand and silt filling interstices between angular to subangular rock fragments. Structure: permeated by small root holes. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: slightly acid. Gradual boundary.
Lackey Creek soil on till of upper member of Placer Creek formation.	36–80	B	Light-yellowish-brown (10*YR* 6/4) very stony sandy till; fragments angular to subangular. Structureless. Consistence: nonsticky, nonplastic, firm, soft. Reaction: medium-acid. Diffuse boundary.
	80–94+	C	Yellowish-brown (10*YR* 5/4) very stony sandy till; fragments, angular to subangular. Structureless. Consistence: friable. Reaction: medium-acid.

Compare this profile with that at higher altitudes, in section 12. At lower altitudes the Brown Podzolic facies becomes progressively less acid until, at about 8,800 feet, a faint horizon of calcium carbonate accumulation marks its change to the Brown Forest facies.

15. *Lackey Creek soil, Brown Podzolic facies*

[Relict profile on till of lower member of Placer Creek formation composed mostly of sandstone. Measured at altitude of about 9,700 feet on terminal moraine on Horse Creek at crossing of Forest Service road leading to Geyser Pass (SW¼SW¼ sec. 3, T. 27 S., R. 24 E.). The vegetation is spruce-fir forest]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Lackey Creek soil on till of lower member of Placer Creek formation.	0–10	A	Dark-reddish-gray (5*YR* 4/2) stony sandy loam. Structure: weak very fine crumb. Consistence: nonsticky, nonplastic, loose. Reaction: slightly acid. Clear boundary.
	10–13	B_1	Light-reddish-brown (5*YR* 6/4) stony sandy loam. Structureless. Consistence: nonsticky, nonplastic, loose. Reaction: medium-acid. Gradual boundary.
	13–50	B_2	Reddish-brown (5*YR* 5/4) stony sandy till. Rock fragments are of sandstone. They are angular to subangular and stained. Structureless. Consistence: slightly sticky, slightly plastic, firm, hard, compact. Reaction: strongly acid. Diffuse boundary.
	50–75+	C	Light-reddish-brown (5*YR* 6/4) stony sandy till. Structureless. Consistence: nonsticky, nonplastic, firm, hard, compact. Reaction: medium-acid.

16. *Lackey Creek soil, Brown Podzolic facies*

[Relict profile on till of lower member of Placer Creek formation composed mostly of Mancos shale. Measured at altitude of about 10,100 feet on terminal moraine at Blue Lake (SE¼NW¼ sec. 7, T. 27 S., R. 25 E.). The vegetation is sagebrush and grass]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Lackey Creek soil on till of lower member of Placer Creek formation.	0–8	A_0	Dark-gray (7.5*YR* 4/1) humic stony sandy silt loam containing large fragments of diorite. Structure: weak medium crumb. Consistence: slightly sticky, nonplastic, very friable, soft. Reaction: slightly acid. Clear boundary.

16. *Lackey Creek soil, Brown Podzolic facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Lackey Creek soil on till of lower member of Placer Creek formation—Continued	8–18	A_1	Light-gray (10*YR* 7/2) stony sandy clay loam. Large rock fragments are mostly of diorite; small fragments are mostly of Mancos shale. Structure: weak medium-to-coarse granular. Consistence: sticky, slightly plastic, firm, hard. Reaction: strongly acid. Diffuse boundary.
	18–36	B	Pale-brown (10*YR* 6/3) stony sandy clay till. Large rock fragments are mostly of diorite; small fragments are mostly of Mancos shale. Structure: moderate fine subangular blocky clay concentrations along structure planes. Consistence: sticky, plastic, firm, very hard. Reaction: medium-acid. Diffuse boundary.
	36–48+	C	Gray-brown (2.5*YR* 5/2) stony sandy clay till. Large rock fragments are of diorite, small fragments are mostly of Mancos shale. Structureless. Consistence: sticky, plastic, firm, very hard. Reaction: medium-acid.

17. *Lackey Creek soil, Brown Podzolic facies*

[Relict profile of poorly drained phase on dioritic till of the upper member of the Placer Creek formation. The poorly drained phase occurs beneath many swamps and marshy areas that lie within the altitude range of the Brown Podzolic facies. It can be traced laterally into the well-drained phase. Measured at altitude of about 9,800 feet, in a swamp along road to South Pass just below its sharp bend at Beaver Lake (NW¼SW¼ sec. 25, T. 27 S., R. 24 E.) The vegetation willow and aspen]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Lackey Creek soil on till of upper member of Placer Creek formation.	0–6	A_0	Very dark brown (10*YR* 2/2) humic silt loam containing abundant roots. Structure: weak fine crumb. Consistence: nonsticky, nonplastic, very friable soft. Reaction: slightly acid. Clear boundary.
	6–12	A_1	Brown (7.5*YR* 5/2) stony fine sandy loam. Structure: moderate fine granular. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: medium-acid. Clear boundary.
	12–30	A_2	Light-gray (10*YR* 7/2) to very pale brown (10*YR* 8/3) stony silty clay loam. Structure: moderate fine angular blocky. Consistence: sticky, plastic, firm, hard. Reaction: very strongly acid. Structural surfaces locally mottled yellowish brown (10*YR* 5/6). Diffuse boundary.
	30–44	B	Light-brown (7.5*YR* 6/4), mottled strong-brown (7.5*YR* 5/8), stony sandy clay till. Grades down in upper few inches to strong brown mottled light brown. Sand is mostly rotted feldspar granules. Structure: moderate fine columnar to fine angular blocky. Some dark manganese staining along structural planes. Consistence: sticky, plastic, firm, hard. Reaction: very strongly acid. Diffuse boundary.
	44–52	C	Yellowish-brown (10*YR* 5/6) stony sandy till. Structureless. Consistence: slightly sticky, slightly plastic, firm, hard. Reaction: very strongly acid.

Evidence that this profile is not primarily the product of its modern swamp environment was found in several places where auger borings showed buried profiles like that above lying beneath several feet of colluvial or eolian silt on which a younger, poorly drained profile, associated with the Castle Creek soil, is developed. The strong brown color of the B horizon is similar to that of well-drained profiles of the Brown Podzolic facies of the Lackey Creek soil and unlike the more reddish or more yellow hues common to bog iron precipitates. This, together with the fact that the light-gray or white A_2 horizon represents a subsequent mottling along structural surfaces surrounding residual strong brown cores, suggests that the profile may first have formed in a well-drained environment in the early part of the Lackey Creek soil-forming interval. The profile became poorly drained during development of the A_2 horizon in the latter part of the interval before being covered at a later time by colluvial or eolian silts of the Beaver Basin formation at a still later time.

18. *Lackey Creek soil, Brown Forest facies*

[Buried profile on till of the lower member of the Placer Creek formation composed mostly of diorite. Measured on a lateral moraine at altitude of about 8,600 feet along the road to Miners Basin at a point about 100 feet from a sharp bend where the road crosses from inner flank of moraine to outer flank (SE¼NE¼ sec. 16, T. 26 S., R. 24 E.). A thin layer of eolian silt of Beaver Basin formation, on which Castle Creek soil is developed, overlies Lackey Creek soil. The vegetation is aspen.]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on eolian silt of Beaver Basin formation that fills interstices between rock fragments on surface of underlying till.	0–12	A	Very dark brown (10*YR* 2/2) humic stony sandy silt loam. Structure: weak fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: slightly acid. Gradual contact.
	12–18	B, C(?)	Very pale brown (10*YR* 7/4) stony fine sand and silt. Rock fragments are stained. Structure: moderate fine crumb. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: slightly acid. Abrupt contact.
Lackey Creek soil on till of lower member of Placer Creek formation.	18–36	B_2	Yellowish-red (5*YR* 5/6) stony sandy till. Rock fragments are stained. Structure: moderate fine subangular blocky. Consistence: slightly sticky, plastic, firm, hard. Reaction: slightly acid. Diffuse boundary.

18. *Lackey Creek soil, Brown Forest facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Lackey Creek soil on till of lower member of Placer Creek formation—Continued	36–54	B_3	Strong-brown (7.5*YR* 5/6) stony sandy till. Rock fragments are stained. Structureless. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: slightly acid. Gradual boundary.
	54–67	Cca	Strong-brown (7.5*YR* 5/6) stony sandy till. Rock fragments are partly stained. Structureless. Consistence: friable. Reaction: neutral to mildly alkaline. Thin calcareous coatings on undersides of some rock fragments. Diffuse boundary.
	67–70+	C	Strong-brown (7.5*YR* 5/6) stony sandy till. Rock fragments are partly stained. Structureless. Consistence: friable. Reaction: slightly acid.

In above profile the color of the upper part of the B horizon is more reddish than that of the B horizon of the Brown Podzolic facies developed on dioritic till. A very weak Cca horizon is marked only by slight encrustations of calcium carbonate on the undersides of some rock fragments. No calcium carbonate accumulated in the matrix.

Compare this section with section 19 of the Brown Forest facies at a lower altitude.

19. *Lackey Creek soil, Brown Forest facies*

[Buried profile on till of lower member of Placer Creek formation composed mostly of diorite. Measured at altitude of about 8,400 feet on a lateral moraine along road to Miners Basin, about 100 yards north of crossing of Placer Creek (NW¼NW¼ sec. 16, T. 26 S., R. 24 E.). A layer of eolian silt of Beaver Basin formation, on which Castle Creek soil is developed, overlies Lackey Creek soil. Compare this section with section 18 of the Brown Forest facies at a higher altitude. The vegetation is aspen and oak]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on eolian silt of Beaver Basin formation.	0–12	A	Very dark gray-brown (10*YR* 3/2) humic stony fine sandy silt loam. Structure: weak very fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: slightly acid. Clear boundary.

19. *Lackey Creek soil, Brown Forest facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on eolian silt of Beaver Basin formation—Con.	12–39	B, C	Light-brown (7.5*YR* 6/4) stony fine sandy silt loam. Structure: moderate fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: slightly acid. Abrupt contact.
Lackey Creek soil on till of Placer Creek formation.	39–69	B_2	Reddish-yellow (7.5*YR* 6/6) stony sandy till. Rock fragments are stained. Structure: weak fine crumb. Consistence: nonsticky, nonplastic, friable, hard. Reaction: slightly acid. Diffuse boundary.
	69–87	B_3	Yellow (10*YR* 7/6) stony sandy till with bedded gravel streaks. Structureless. Consistence: nonsticky, nonplastic, friable, hard. Reaction: neutral. Diffuse boundary.
	87–130	Cca	Very pale brown (10*YR* 7/3) stony sandy till with bedded gravel streaks. Structureless. Consistence: friable, slightly hard. Calcium carbonate forms thin coating on cobbles and weakly cements matrix in streaks. Reaction: moderately alkaline. Diffuse boundary.
	130–230 +	C	Very pale brown (10*YR* 7/4) stony sandy till with bedded gravel streaks. Consistence: friable, slightly hard. Reaction: neutral to mildly alkaline.

20. *Lackey Creek soil, Brown Forest facies*

[Relict profile on eolian sand and silt of the Placer Creek formation. Measured at altitude of about 7,800 feet along irrigation ditch near old road to South Pass, where it crosses edge of terrace on south side of La Sal Creek (NW¼SE¼ sec. 17, T. 28 S., R. 25 E.). The vegetation is sagebrush and oak]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Lackey Creek soil on eolian sand and silt of Placer Creek formation.	0–5	A	Dark-brown (10*YR* 4/2) humic fine sandy silt loam. Structure: moderate medium crumb. Consistence: nonsticky, nonplastic, very friable, slightly hard Reaction: neutral. Clear boundary.

20. *Lackey Creek soil, Brown Forest facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Lackey Creek soil on eolian sand and silt of Placer Creek formation—Con.	5–20	B_1	Reddish-brown (2.5*YR* 5/4) fine sandy silt loam. Structure: weak fine subangular blocky. Consistence: slightly sticky, slightly plastic, friable, slightly hard. Reaction: slightly acid. Gradual boundary.
	20–38	B_2	Yellowish-red (5*YR* 5/6) fine sandy silt loam. Structure: weak medium subangular blocky. Consistence: sticky, plastic, firm, hard. Reaction: slightly acid to neutral. Abrupt boundary.
	38–40	Cca	Light-reddish-brown (5*YR* 5/4) fine sandy silt loam. Structureless. Consistence: slightly sticky, slightly plastic, firm, hard. Reaction: mildly alkaline. Some calcareous concentrations along root casts. Abrupt contact.
	40–60	Cca	Light-reddish-brown (5*YR* 6/4) sandy gravel. Gravel composed mostly of diorite, crudely bedded. Thin calcareous coatings on undersides of some pebbles.

21. *Lackey Creek soil, Brown soil facies*

[Relict profile on alluvial gravel of lower member of Placer Creek formation composed mostly of diorite. Measured along State Highway 46 in valley of La Sal Creek in borrow pit at altitude of about 7,500 feet (NW¼SW¼ sec. 10, T. 28 S., R. 25 E.). The vegetation is sagebrush]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Lackey Creek soil on alluvial gravel of lower member of Placer Creek formation.	0–4	A	Very dark brown (7.5*YR* 3/4) humic gravelly sandy loam. Structure: weak fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: mildly alkaline. Gradual boundary.

21. *Lackey Creek soil, Brown soil facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Lackey Creek soil on alluvial gravel of lower member of Placer Creek formation—Continued	4–22	B	Brown (7.5*YR* 4/4) sandy gravel. Structure: weak subangular blocky with spherical and cylindrical masses 10 to 20 millimeters in diameter that have concentric structure and which are probably insect nests. Consistence: slightly sticky, slightly plastic, friable, hard. Reaction: mildly alkaline. Clear boundary.
	22–80	Cca	Very pale brown (10*YR* 8/3) to white (10*YR* 8/2) sandy gravel. Structure: moderate to strong medium platy. Consistence: nonsticky, nonplastic, firm, hard. Reaction: strongly alkaline. Diffuse boundary.
	80–96+	C	Brownish-yellow (10*YR* 6/4) sandy gravel with sand lenses, crudely bedded. Consistence: nonsticky, nonplastic, firm, hard. Reaction: mildly alkaline.

22. *Lackey Creek soil, Brown soil facies*

[Buried profile on alluvial sand and silt of Placer Creek formation. Measured at type locality of Lackey Creek soil at altitude of about 6,700 feet, in wall of Lackey Creek just downstream from crossing of State Highway 46, 2½ miles west of La Sal (NW¼SW¼ sec. 4, T. 29 S., R., 24 E.)(fig. 28). The vegetation is sagebrush]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Younger superposed soil of unknown stratigraphic affinity.	0–10	A	Brown (7.5*YR* 5/4) slightly humic fine sand and silt. Structureless. Consistence: loose. Reaction: mildly alkaline. Abrupt boundary.
Castle Creek soil on alluvial sand and silt of Beaver Basin formation.	10–22	A	Dark-brown (7.5*YR* 4/2) humic sandy loam, darker in top inch. Structure: weak fine crumb. Consistence: nonsticky nonplastic, very friable, slightly hard. Reaction: midly alkaline. Diffuse boundary.

22. *Lackey Creek soil, Brown soil facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on alluvial sand and silt of Beaver Basin formation—Continued	22–76	B, Cca	Brown (7.5*YR* 5/4) sandy loam. Structure: moderate subangular blocky to fine columnar, with spherical and cylinrical insect nests 10 to 20 millimeters in diameter that have a concentric structure; numerous small root holes and a few large krotovinas. Weakly bedded locally. Consistence: nonsticky nonplastic, friable, hard; calcareous films along roots and structural openings. Reaction: mildly alkaline. Abrupt disconformity.
Lackey Creek soil on alluvial sand and silt of Placer Creek formation.	76–86	B_1	Reddish-brown (5*YR* 4/3) humic sandy silt loam. Structure: locally platy at top, weak medium columnar. Consistence: sticky, nonplastic, firm, very hard. Reaction: mildly alkaline. Lime concentrated as thin films along root holes. This horizon is locally cut out by disconformity. Gradual boundary.
	86–110	B_2	Reddish-brown (5*YR* 5/4) sandy silt with local interbedded gravel in lower part. Structure: weak coarse angular blocky. Consistence: nonsticky, nonplastic, firm, very hard. Reaction: mildly alkaline. This horizon is locally cut out by disconformity. Gradual boundary.

22. *Lackey Creek soil, Brown soil facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Lackey Creek soil on alluvial sand and silt of Placer Creek formation—Con.	110–160	Cca	Light-reddish-brown (5*YR* 6/4) fine sandy silt and interbedded cobble gravel, with pink (5*YR* 8/3) streaks and concentrations along root holes. Structure: weak fine columnar locally platy. Consistence: nonsticky, nonplastic, firm, very hard, weakly to strongly cemented with carbonate. Reaction: strongly alkaline. Cobbles and matrix are both heavily coated with lime. Diffuse boundary.
	160–180+	C	Grayish dioritic cobble gravel and reddish-yellow (10*YR* 5/6) silty sand. Bedded, firm, hard; mostly free of calcareous coatings. Reaction: moderately alkaline.

At this locality, the Lackey Creek soil can be traced from a relict position, in the vicinity of the road crossing, to a point where it is overlapped by alluvial sand and silt of the Beaver Basin formation on which the Castle Creek soil is developed. Farther downstream it passes from sight beneath the stream bed.

23. *Lackey Creek soil, Sierozem facies*

[Relict profile on alluvial gravel of the Placer Creek formation composed mostly of diorite. Measured at altitude of about 4,200 feet in Spanish Valley, on a terrace half a mile southeast of Moab near water tank where U.S. Highway 450 crosses Pack Creek (SE¼SE¼ sec. 6, T. 26 S., R. 22 E.). The vegetation is sagebrush]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Lackey Creek soil on alluvial gravel of Placer Creek formation.	0–8	A	Reddish-brown (5*YR* 5/4) fine sand and silt. Structure: weak medium crumb. Consistence: nonsticky, nonplastic, friable, soft. Reaction: moderately alkaline. Clear contact.
	8–14	Bca	Reddish-brown (2.5*YR* 5/4) mottled light reddish-brown (2.5*YR* 6/4), fine sandy silt loam. Structure: moderate medium subangular blocky. Consistence: slightly sticky, slightly plastic, friable, slightly hard. Reaction: strongly alkaline. This unit is locally missing, and the A horizon rests directly on the Cca horizon. Gradual boundary.
	14–100+	Cca	Light-reddish-brown (2.5*YR* 6/4) cobble gravel and sand, crudely bedded. Consistence: firm, hard, weakly cemented. Reaction: strongly alkaline. Where overlain directly by A horizon, contact is a very sharp line of leaching on the cobbles. Upper sides of cobbles are free of coating; lower sides are thickly coated, with calcareous projections 2 to 3 inches long extending down into interstitial voids. Diffuse contact.
	100–300+	C	Reddish-brown (5*YR* 5/4) cobble gravel and sand, with some sand layers, crudely bedded. Consistence: friable, slightly hard. Reaction: moderately alkaline. Local streaks in which gravel is thinly coated with lime.

24. *Pack Creek soil, Brown Podzolic facies*

[Buried profile on alluvial gravel of lower member of Beaver Basin formation composed of diorite. Measured at altitude of about 8,100 feet, in bluff bordering Pack Creek (SW¼NE¼ sec. 32, T. 27 S., R. 24 E.). Pack Creek soil is overlain by alluvial gravel of upper member of Beaver Basin formation on which Brown Podzolic facies of Castle Creek soil is developed. This in turn is overlain by gravelly alluvium of lower member of Gold Basin formation on which Pedalfer facies of Spanish Valley soil is developed. The vegetation is aspen]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Spanish Valley soil on alluvium of lower member of Gold Basin formation.	0–6	A	Very dark gray (10*YR* 3/1) humic gravelly sandy silt loam. Structure: very fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: slightly acid. Gradual boundary.
	6–48	C	Brown (10*YR* 5/3) gravelly sandy alluvium, locally humic. Structureless. Consistence: nonsticky. nonplastic, very friable, soft. Reaction: slightly acid. Abrupt disconformity.
Castle Creek soil on alluvium of upper member of Beaver Basin formation.	48–66	A	Very dark gray (10*YR* 3/1) humic gravelly sandy silt loam. Structure: very fine granular. Consistence: nonsticky. nonplastic, very friable, soft. Reaction: slightly acid. Gradual boundary.
	66–76	B	Brown (7.5*YR* 5/4) gravelly sand and silt. Structure: very fine crumb. Consistence: nonsticky. nonplastic, friable, firm. Reaction: slightly acid. Gradual boundary.
	76–132	C	Brown (10*YR* 5/3) sandy gravel. Structureless. Consistence: nonsticky. nonplastic, friable, slightly hard. Reaction: slightly acid. Abrupt disconformity.
Pack Creek soil on alluvium of lower member of Beaver Basin formation.	132–150	A	Dark-gray (10*YR* 4/1) humic gravelly sandy silt loam. Structure: very fine angular blocky. Consistence: slightly, sticky, slightly plastic, firm, hard. Reaction: slightly acid. Gradual boundary.

24. *Pack Creek soil, Brown Podzolic facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Pack Creek soil on alluvium of lower member of Beaver Basin formation—Con.	150–154	B	Brown (10*YR* 5/4) gravelly sand and silt. Structureless. Consistence: slightly sticky, slightly plastic, firm, hard. Reaction: slightly acid. Diffuse boundary.
	154–300	C	Brown (10*YR* 5/3) sandy gravel. Structureless. Consistence: nonsticky, nonplastic, firm, hard. Reaction: slightly acid.

25. *Pack Creek soil, Brown Forest facies*

[Buried profile on alluvial sandy gravel of the lower member of the Beaver Basin formation composed mainly of diorite. Section is stratigraphic type locality of Pack Creek soil and was measured at altitude of about 7,500 feet, in the bluff bordering Pack Creek just above the national forest boundary (SW¼NE¼ sec. 31, T. 27 S., R. 24 E.) (fig. 40). The Pack Creek soil is overlain by gravelly sand and silt of upper member of Beaver Basin formation on which Brown Forest facies of Castle Creek soil is developed. This, in turn, is overlain by modern natural levee material deposited during dissection of the arroyo that contains Pack Creek. The vegetation is oak brush]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Modern natural levee deposit.	0–30		Gray-brown (10*YR* 5/2) gravelly sandy loam. Structureless: Consistence: very friable, soft. Reaction: slightly acid. Abrupt disconformity.
Castle Creek soil on alluvium of upper member of Beaver Basin formation.	30–42	A	Very dark gray (10*YR* 3/1) humic gravelly, sandy silt loam. Structure: very fine granular to weak very fine angular blocky thin platy in upper 6 inches. Consistence: nonsticky, nonplastic, friable, hard. Reaction: slightly acid. Gradual boundary.
	42–60	B	Brown (7.5*YR* 5/4) gravelly sandy silt loam. Structure: weak fine prismatic to very fine angular blocky permeated by small root holes; some krotovinas. Consistence: nonsticky, slightly plastic, firm, hard. Reaction: slightly acid to neutral. Gradual boundary.

25. *Pack Creek soil, Brown Forest facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on alluvium of upper member of Beaver Basin formation—Con.	60–86	Cca	Brown (10*YR* 5/3) sandy silty boulder gravel. Structure of matrix: very fine angular blocky. Consistence: nonsticky, slightly plastic, firm, hard. Reaction: mildly alkaline. Calcareous films on fragments. Gradual boundary.
	86–130	C	Gray-brown (10*YR* 5/2), with local rusty streaks, sandy silty boulder gravel. Structureless. Consistence: nonsticky, nonplastic, friable, hard. Reaction: mildly alkaline. Some secondary carbonate. Disconformity.
Pack Creek soil on alluvium of lower member of Beaver Basin formation.	130–142	A	Gray (10*YR* 5/1) humic sandy silt loam. Structureless. Consistence: nonsticky, nonplastic, firm, hard. Reaction: slightly acid but with secondary carbonate films along bedding planes and root casts. Local rusty streaks. Thin horizon of oxide accumulation at base may be a B horizon. Clear boundary.
	142–152	Cca	Very pale brown (10*YR* 7/4) sandy silt loam. Structure: massive. Consistence: nonsticky, nonplastic, firm, hard. Reaction: mildly alkaline; spangled with lime along many small root casts. Some lime may be of secondary origin, as are local rusty streaks. Clear boundary.
	152–160	Cca	Light-brown (7.5*YR* 6/4) subangular boulder gravel and sand. Structure: crudely bedded; no soil structure. Consistence of matrix: nonsticky, nonplastic, friable, slightly hard. Reaction: mildly alkaline; thin films of lime on pebbles and cobbles.
Pack Creek soil on alluvium of lower member of Beaver Basin formation—Con.	160–242	C	Light-brown (7.5*YR* 6/4) boulder gravel as above. Calcareous films rare and probably of secondary origin.

26. *Pack Creek soil, Brown soil facies*

[Buried profile on alluvial gravel of the lower member of the Beaver Basin formation composed mainly of diorite. Measured at altitude of about 6,600 feet in scarp of a terrace about 20 feet above Pack Creek near a ranch on its north bank, half a mile west of Hell Canyon (NW¼NW¼ sec. 30, T. 27 S., R. 24 E.). The Pack Creek soil is overlain by alluvial sand and gravel of upper member of Beaver Basin formation on which Brown soil facies of Castle Creek soil is formed. The vegetation is sagebrush]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on alluvium of upper member of Beaver Basin formation.	0–12	A	Very dark gray (10*YR* 3/1) humic sandy silt loam. Structure: weak fine granular to weak angular blocky. Consistence: nonsticky, nonplastic, friable, soft. Reaction: slightly acid to neutral. Gradual boundary.
	12–22	B	Brown (7.5*YR* 5/4) sandy silt loam. Structureless. Consistence: nonsticky, nonplastic, friable, soft. Reaction: neutral to mildly alkaline. Gradual boundary.
	22–50	Cca	Brown (7.5*YR* 5/3) sandy silt. Structureless. Consistence: nonsticky, nonplastic, friable, soft. Reaction: moderately alkaline. Gradual boundary.
	50–72	C	Gray-brown (10*YR* 5/2) sandy gravel. Structure: crudely bedded. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: moderately alkaline. Abrupt disconformity.

26. *Pack Creek soil, Brown soil facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Pack Creek soil on alluvium of lower member of Beaver Basin formation.	72–78	A	Gray (10*YR* 5/1) sandy silt loam. Structure: weak fine subangular blocky. Consistence: nonsticky, slightly, plastic, firm, hard. Reaction: slightly acid except for secondary carbonate accumulations along root casts and structural openings. Clear boundary.
	78–83	B	Brown (7.5*YR* 5/4) silty sand. Structureless. Consistence: nonsticky, slightly plastic, firm, hard. Reaction: mildly alkaline. Gradual boundary.
	83–90	Cca	Light-brown (7.5*YR* 6/4) silty sand. Structureless. Consistence: nonsticky, slightly plastic, firm, hard. Reaction: moderately alkaline. Clear boundary.
	90–110	Cca	Light-brown (7.5*YR* 6/4) sandy gravel. Structure: crudely bedded. Consistence: friable, slightly hard. Reaction: moderately alkaline. Thin films of carbonate on rock fragments. Diffuse boundary.
	110–240	C	Light-brown sandy gravel, as above, but mildly alkaline to neutral. No carbonate films.

27. *Pack Creek soil, Brown soil facies*

[Buried profile on eolian sand and silt of the lower member of the Beaver Basin formation. Measured at altitude of about 7,200 feet in wall of deeply eroded irrigation ditch on the south side of Burkholder Draw northeast of North Mesa (NE¼SE¼ sec. 11, T. 26 S., R. 23 E.). The vegetation is sagebrush]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on eolian sand and silt of upper member of Beaver Basin formation.	0–3	A	Dark-reddish-gray (5*YR* 4/2) humic silt. Structure: moderate very thin platy. Consistence: slightly sticky, nonplastic, very friable, slightly hard. Reaction: neutral. Clear boundary.

27. *Pack Creek soil, Brown soil facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on eolian sand and silt of upper member of Beaver Basin formation—Con.	3–7	B	Reddish-brown (5*YR* 4/2) silt. Structure: moderate thin platy to angular blocky. Consistence: slightly sticky, slightly plastic, friable, hard. Reaction: neutral. Gradual boundary.
	7–42	Cca	Light-reddish-brown (5*YR* 6/3) silt, interlaced with white lime concentrations along structure planes and root casts. Structure: strong fine columnar. Consistence: sticky, slightly plastic, firm, hard. Reaction: moderately alkaline. Abrupt disconformity.
Pack Creek soil on eolian sand and silt of upper member of Beaver Basin formation.	42–54	A	Reddish-gray (5*YR* 5/2) silt, interlaced with white secondary carbonate along structure planes and small root casts. Structure: moderate fine columnar. Consistence: slightly sticky, slightly plastic, friable, hard. Reaction: slightly acid, except mildly alkaline along root casts and structural openings. Clear boundary.
	54–62	B	Reddish-brown (5*YR* 5/4) silt. Structure: massive to weak fine columnar; a few small root casts. Consistence: slightly sticky, slightly hard. Reaction: mildly alkaline to slightly acid; secondary carbonate along root casts. Gradual boundary.
	62–74	Cca	Light-reddish-brown (5*YR* 6/4) silt. Structureless to weak thin platy. Consistence: nonsticky nonplastic, friable, slightly hard. Reaction: moderately alkaline. Abrupt disconformity.

27. *Pack Creek soil, Brown soil facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Lackey Creek soil on eolian sand and silt of Placer Creek formation.	74–100	B	Reddish-brown (5*YR* 5/4) silt. Structure: strong fine columnar permeated by small root casts. Consistence: sticky, plastic, friable, hard. Reaction: slightly acid to mildly alkaline, weak carbonate concentrations along roots in a few places. Gradual boundary.
	100–160	Cca	Reddish-brown (5*YR* 5/3) silt, spangled with white lime concentrations along root casts. Structureless. Consistence: slightly sticky, slightly plastic, very friable, hard. Reaction: moderately alkaline. Diffuse boundary.
	160–200	C	Pink (5*YR* 7/3) silt. Structure: strong thick platy. Consistence: slightly sticky, slightly plastic, friable, hard. Reaction: strongly alkaline. Carbonate probably concentrated by water moving along contact beneath. Sharp contact against sandstone bedrock permeated with lime.

At this locality three generations of eolian sand and silt are exposed (fig. 39). The oldest deposits have the Lackey Creek soil developed on them and belong to the Placer Creek formation. These are overlain by deposits of the lower member of the Beaver Basin formation on which the Pack Creek soil is developed, and these, in turn, are overlain by deposits of the upper member on which the Castle Creek soil is developed.

28. *Pack Creek soil, Sierozem facies*

[Buried profile on alluvial sand and silt of the lower member of the Beaver Basin formation. Measured at altitude of about 4,100 feet on south side of Pack Creek at bridge on county road southeast of Moab (SW¼ NW¼ sec. 7, T. 26 S., R. 22 E.). The Pack Creek soil is overlain by upper member on which Castle Creek soil is developed. This soil, in turn, is overlain by alluvium of lower member of Gold Basin formation on which the very weakly developed Spanish Valley soil is formed (fig. 42). The vegetation is sagebrush.]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Spanish Valley soil on alluvium of lower member of Gold Basin formation.	0–2	A	Reddish-gray (5*YR* 4/2) humic fine sand and silt. Structure: moderate very thin platy. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: moderately alkaline. Clear boundary.
	2–12	Cca	Reddish-brown (2.5*YR* 5/4) fine sand and silt. Structureless. Consistence: loose. Reaction: moderately alkaline. Abrupt disconformity.
Castle Creek soil on alluvium of upper member of Beaver Basin formation.	12–22	A	Weak-red (2.5*YR* 5/2) humic, fine sand and silt. Structure: weak coarse blocky. Consistence: nonsticky, nonplastic., friable, slightly hard. Reaction: moderately alkaline. Clear boundary.
	22–34	Cca	Light-reddish-brown (5*YR* 6/4) fine sand and silt. Structure: weakly bedded. Consistence: friable, slightly hard. Reaction: moderately alkaline. Abrupt disconformity.
Pack Creek soil on alluvium of lower member of Beaver Basin formation.	34–42	A	Reddish-gray (5*YR* 5/2) humic fine sand and silt. Structure: weak coarse blocky. Consistence: friable, slightly hard. Reaction: moderately alkaline. Clear boundary.

28. *Pack Creek soil, Sierozem facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Pack Creek soil on alluvium of lower member of Beaver Basin formation—Con.	42–66	Cca	Light-reddish-brown (5*YR* 6/4) fine sand and silt. Structure: massive. Consistence: friable, soft. Reaction: moderately alkaline. Diffuse boundary.
	66–210	C	Light-reddish-brown (5*YR* 6/3) fine sand and silt with interlayered fine gravel and local humic lenses. Weak channelled bedding. Consistence: soft. Reaction: mildly alkaline.

Another profile of the Sierozem facies of the Pack Creek soil developed on alluvial sand and silt of the lower member of the Beaver Basin formation is described in section 40.

29. *Castle Creek soil, Brown Podzolic facies*

[Relict profile on till of upper member of Beaver Basin formation conposed mostly of diorite. Measured at altitude of about 11,000 feet on crest of terminal moraine of upper member of Beaver Basin formation on north side of Beaver Basin (NW¼NE¼ sec. 24, T. 26 S., R. 24 E.). The upper foot or so of the till contains a considerable proportion of eolian quartz sand and silt, a condition typical of most moraines of the Beaver Basin formation. The vegetation is spruce and grass]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on till of upper member of Beaver Basin formation.	0–4	A	Very dark brown (10*YR* 2/2) humic sandy silt loam with a few rock fragments. Structure: fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: medium-acid. Clear boundary.
	4–10	B_1	Pale-brown (10*YR* 6/3) stony sandy silt loam. Structure: weak very fine subangular blocky to fine crumb. Consistence: nonsticky, nonplastic to slightly plastic, friable, slightly hard. Reaction: strongly acid. Gradual boundary.
	10–18	B_2	Yellowish-brown (10*YR* 5/4) very stony sandy till. Structure: weak very fine subangular blocky. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: strongly acid. Diffuse boundary.

29. *Castle Creek soil, Brown Podzolic facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on till of upper member of Beaver Basin formation—Continued	18–26	B_3	Light-yellowish-brown (10*YR* 6/4) very stony sandy till. Structureless. Consistence: friable, slightly hard. Reaction: strongly acid. Diffuse boundary.
	26–48+	C	Pale-brown (10*YR* 7/4) very stony sandy till. Structureless. Consistence: friable, slightly hard. Reaction: strongly acid.

30. *Castle Creek soil, Brown Podzolic facies*

[Relict profile on solifluction mantle of the Beaver Basin formation composed of diorite. Measured at altitude of about 12,000 feet on south slope of Manns Peak (NW¼NW¼ sec. 25, T. 26 S., R. 24 E.). Eolian quartz sand snd silt is mixed with upper few inches of solifluction mantle. The vegetation is alpine tundra]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on solifluction mantle of Beaver Basin formation.	0–2	A	Very dark brown (10*YR* 2/2) humic stony silt loam. Structure: very fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: medium-acid. Clear boundary.
	2–8	B_1	Light-brown (7.5*YR* 6/3) stony sandy silt loam. Structure: fine crumb. Consistence: nonsticky, very slightly plastic, friable, soft. Reaction: strongly acid. Gradual boundary.
	8–16	B_2	Brown (7.5*YR* 5/4) stony sandy solifluction mantle. Structureless. Consistence: slightly plastic, friable, soft. Reaction: strongly acid. Diffuse boundary.
	16–24	B_3	Light-yellowish-brown (10*YR* 6/4) stony sandy solifluction mantle. Structureless. Consistence: friable, slightly hard. Reaction: strongly acid. Diffuse boundary.
	24–36+	C	Pale-brown (10*YR* 6/3) stony sandy solifluction mantle. Structureless. Consistence: friable, slightly hard. Reaction: strongly acid.

Note similarity between this profile on solifluction mantle and that developed on till in section 29.

31. *Castle Creek soil, Brown Podzolic facies*

[Relict profile developed on till of the lower member of the Beaver Basin formation composed mostly of sandstone. Measured at altitude of about 10,000 feet in the valley of Mill Creek at a point where lateral moraine of lower member is crossed by the road to Geyser Pass (SW¼NW¼ sec. 2, T. 27 S., R. 24 E.). Fine sand and silt of eolian origin is mixed with upper 12 inches of till. The vegetation is spruce forest]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on till of lower member of Beaver Basin formation.	0–2	A_0	Very dark gray (10*YR* 4/1) duff.
	2–6	A_1	Gray-brown (10*YR* 5/2) humic light silt loam. Structure: very fine crumb. Consistence: nonsticky, slightly plastic, very friable, soft. Reaction: medium-acid. Gradual boundary.
	6–12	B_2	Brown (7.5*YR* 5/2) slightly humic stony silt. Structureless to very fine crumb. Consistence: nonsticky, slightly plastic, very friable, soft. Reaction: medium-acid. Gradual boundary.
	12–20	B_3	Pinkish-gray (7.5*YR* 6/2) stony sandy silt. Structureless. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: strongly acid. Gradual boundary.
	20–28	B_3	Light-brown (7.5*YR* 6/4) stony sandy till. Structure: weak fine subangular blocky. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: strongly acid. Diffuse boundary.
	28–44+	C	Pinkish-gray (7.5*YR* 7/2) stony sandy till. Structureless. Consistence: nonsticky, nonplastic, friable, hard, moderately compact. Reaction: strongly acid.

32. *Castle Creek soil, Brown Podzolic facies*

[Relict profile on till of the upper member of the Beaver Basin formation composed mostly of clay derived from the Mancos shale. Measured at altitude of about 11,200 feet on end moraine of upper member below north cirque at head of Dark Canyon (SE¼NW¼ sec. 13, T. 27 S., R. 24 E.). The vegetation is grass]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on till of upper member of Beaver Basin formation.	0–4	A	Gray-brown (10*YR* 5/2) humic silty loam and rock fragments. Structure: weak fine crumb. Consistence: nonsticky, slightly plastic, very friable, soft. Reaction: medium-acid. Gradual boundary.
	4–10	B	Brown (10*YR* 5/3) silty clay loam and rock fragments. Structure: weak fine subangular blocky. Consistence: sticky, plastic, firm, slightly hard. Reaction: medium-acid. Diffuse boundary.
	10–24+	C	Dark-gray-brown (2.5*YR* 4/2) stony clay till. Structureless. Consistence: sticky, plastic, firm, slightly hard. Reaction: medium-acid.

33. *Castle Creek soil, Brown Podzolic facies*

[Relict profile on eolian sand and silt of the Beaver Basin formation. Measured at altitude of about 10,800 feet near top of north-facing slope of Miners Basin along trail to Dry Fork (NW¼NE¼ sec. 22, T. 26 S., R. 24 E.). At this locality, the eolian deposits, on which the Brown Podzolic facies is developed, rest conformably on solifluction mantle of Beaver Basin formation. The vegetation is spruce forest]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on eolian silt of Beaver Basin formation.	0–1	A_1	Forest litter. Abrupt boundary.
	1–2	A_2	Brown (7.5*YR* 5/3) humic silt. Structure: weak very thin platy. Consistence: light, nonsticky, nonplastic, very friable, soft. Reaction: medium-acid. Clear boundary.

33. *Castle Creek soil, Brown Podzolic facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on eolian silt of Beaver Basin formation—Con.	2–6	B_2	Light-brown (7.5*YR* 6/3) silt. Structure: weak very fine crumb. Consistence: light, nonsticky, nonplastic, very friable, soft. Reaction: strongly acid. Gradual boundary.
	6–16	B_3	Brown (7.5*YR* 5/2) silt. Structure: weak very fine crumb. Consistence: nonsticky, slightly plastic, friable, soft. Reaction: slightly acid. Diffuse boundary.
	16–26	C	Pinkish-gray (7.5*YR* 6/3) silt. Structureless. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: slightly acid. Disconformity.
Solifluction mantle of Beaver Basin formation.	26–28	C	Light-brown (7.5*YR* 6/4) stony sandy solifluction mantle. Structureless. Consistence: friable, slightly hard. Reaction: slightly acid. Gradual boundary.
	28–40+	C	Brown (7.5*YR* 5/2) stony sandy solifluction mantle. Structureless. Consistence: friable, slightly hard. Reaction: slightly acid.

Where eolian mantle of the Beaver Basin formation rests on stony deposits of the Placer Creek or Harpole Mesa formations, a zone of rock fragments and voids is commonly present at the contact above a truncated profile of the Lackey Creek or Spring Draw soil. Such a profile is given in the description of the Brown Podzolic facies of the Lackey Creek soil (section 12).

34. *Castle Creek soil, Brown Podzolic facies*

[Profile on eolian quartz sand and silt in interstices of frost rubble at depth below surface. Measured at altitude of about 10,800 feet in a rubble sheet on south ridge of Miners Basin at head of Schuman Gulch (NE¼NW¼ sec. 22, T. 26 S., R. 24 E.). The vegetation is sparse lichen on boulders. Grass and spruce are around borders of deposit]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Rubble sheet of Beaver Basin formation.	0–24		Blocks of diorite, 6 inches to 2 feet in diameter, with interstitial voids. Abrupt boundary.
Castle Creek soil on eolian silt in interstices of rubble sheet.	24–27	A	Dark-gray-brown (10*YR* 4/2) humic silt in interstices between blocks. Structure: weak fine crumb. Consistence: slightly sticky, slightly plastic, very friable, soft. Reaction: slightly acid. Gradual boundary.
	27–47	B_2	Very pale brown (10*YR* 7/4) light fluffy silt in voids between blocks. Structure: weak fine crumb permeated by very small holes. Consistence: slightly sticky, plastic, friable, slightly hard. Reaction: slightly acid. Diffuse boundary.
	47–57	B_3	Pink (7.5*YR* 7/4) sandy silt and small rock fragments partly filling interstices between blocks. Structure: weak fine subangular blocky. Consistence: nonsticky, slightly plastic, friable, slightly hard. Reaction: medium-acid. Diffuse boundary.
	57–70+	C	Pinkish-gray (7.5*YR* 7/2) silty sand and small rock fragments in interstices of closely spaced rock fragments that become increasingly tightly fitted downward until they merge with fractured but undisplaced bedrock. Structureless. Consistence: nonsticky, nonplastic, loose. Reaction: medium-acid.

Obviously, the eolian material was emplaced after formation of the rubble sheet. Restriction of organic matter to the relatively thin A horizon of the soil further suggests that eolian activity ceased before soil development began. Compare with section 35.

35. *Castle Creek soil, Brown Podzolic facies*

[Profile on eolian quartz sand silt in interstices of rubble sheet at depth below surface. Measured at altitude of 9,600 feet at drift fence along road to Miners Basin (SE¼NE¼ sec. 16, T. 26 S., R. 24 E.). Vegetation is sparse lichen on boulders. Aspen is on slopes bordering deposit]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Rubble stream of Beaver Basin formation.	0–40		Subangular boulders and cobbles, 6 inches to 3 feet in diameter, with interstitial voids. Abrupt contact.

35. *Castle Creek soil, Brown Podzolic facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on eolian silt in interstices of rubble stream.	40–52	A	Very dark gray-brown (10*YR* 3/2) humic fine sandy silt loam in interstices between rock fragments; contains some roots. Structure: weak very fine crumb. Consistence: nonsticky, slightly plastic, very friable, soft. Reaction: slightly acid. Gradual boundary.
	52–94	B, C	Dark-gray-brown (10*YR* 4/2) humic fine sandy silt filling interstices between rock fragments. Structure: weak fine subangular blocky. Consistence: slightly sticky, slightly plastic, friable, slightly hard. Reaction: slightly acid. Abrupt disconformity.
Till of lower member of Placer Creek formation.	94–104		Yellowish-brown (10*YR* 5/4) water stain on bouldery sandy till. Structureless. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: slightly acid. Diffuse boundary.
	104–115+		Light-yellowish-brown (10*YR* 6/4) bouldery sandy till. Structureless. Consistence: nonsticky, nonplastic, firm, hard. Reaction: slightly acid.

The yellowish-brown zone of oxide accumulation at the top of the till was probably precipitated from water moving along the base of the silt on the till. This zone is not related to the Lackey Creek soil which is developed on the till on either side of the block stream but which has been truncated by the development of the block stream as shown in figure 34.

Eolian silt fills the interstices of a rubble stream of the Beaver Basin formation that is developed on a lateral moraine of the Placer Creek formation (fig. 34). Distribution of organic matter throughout the profile and the lack of clear distinction between the B and C horizons suggests that eolian deposition and soil development may have been, at least in part, contemporaneous.

36. *Castle Creek soil, calcareous phase in the range of the Brown Podzolic facies*

[Profile on eolian quartz sand and silt in interstices of rubble sheet of Beaver Basin formation. Measured at altitude of about 11,050 feet on Gold Knob (NE¼NE¼ sec. 21, T. 26 S., R. 24 E.). The vegetation is grass]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on rubble sheet of Beaver Basin formation.	0–1	A	Dark-gray-brown (10*YR* 4/2) humic silt loam filling interstices between rock fragments. Structure: weak fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: neutral. Clear boundary.
	1–10	B	Dark-brown (7.5*YR* 4/3) humic sandy silt loam filling interstices between rock fragments. Structure: weak fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: neutral. Gradual boundary.
	10–18	Bca	Brown (7.5*YR* 5/4) eolian quartz sandy silt partly filling interstices between rock fragments. Structureless. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: neutral. Thin calcareous coatings on undersides of some rock fragments. Diffuse boundary.
	18–42	Cca	Brown (7.5*YR* 5/4) eolian quartz sandy silt and small angular rock fragments partly filling interstices between rock fragments. Structureless. Consistence: nonplastic, very friable. Reaction: mildly alkaline. Calcareous coatings on undersides of most rock fragments. Diffuse boundary.
	42–54+	C	Pinkish-gray (7.5*YR* 7/2) eolian quartz silt and small angular rock fragments in interstices between closely spaced blocks that become increasingly tightly fitted downward until they merge with fractured but undisplaced bedrock. Structureless. Consistence: loose. Reaction: neutral.

37. *Castle Creek soil, Brown Forest facies*

[Relict profile on alluvial gravel of the Beaver Basin formation composed mainly of diorite. Measured at altitude of about 7,500 feet, in wall of Lackey Creek on south side of mountains (SW¼NW¼ sec. 27, T. 28 S., R. 24 E.). The vegetation is sagebrush and oak]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on alluvial gravel of Beaver Basin formation.	0–8	A	Dark-gray-brown (10*YR* 5/2) humic stony fine sandy loam. Structure: moderate fine crumb. Consistence: nonsticky, nonplastic, very friable, slightly hard. Reaction: slightly acid. Gradual boundary.
	8–16	B	Light-brown (7.5*YR* 6/4) sandy gravel. Structureless to crudely bedded. Consistence: very friable. Reaction: slightly acid to neutral. Gradual boundary.
	16–28	Cca	Light-brown (7.5*YR* 6/4) sandy gravel. Structureless to crudely bedded. Consistence: very friable. Reaction: mildly alkaline. Filmy calcareous coatings on cobbles. Diffuse boundary.
	28+	C	Light-brown (7.5*YR* 6/4) sandy gravel. Structureless to crudely bedded. Consistence: very friable. Reaction: neutral to slightly acid.

A profile of the Brown Forest facies of the Castle Creek soil developed on alluvial sand and silt of the upper member of the Beaver Basin formation is described in section 25.

38. *Castle Creek soil, Brown soil facies*

[Relict profile on alluvial gravel of the Beaver Basin formation composed mainly of diorite. Measured at altitude of about 5,700 feet at edge of a terrace 20 feet above Pack Creek near crossing of Forest Service road below Pack Creek Ranch (NW¼NW¼ sec. 22, T. 27 S., R. 23 E.). The vegetation is sagebrush association]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on alluvial gravel of Beaver Basin formation.	0–6	A	Dark-gray-brown (10*YR* 4/2) humic sandy silt loam. Structure: fine crumb. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: mildly alkaline. Gradual boundary.

38. *Castle Creek soil, Brown soil facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on gravel of Beaver Basin formation—Continued	6–12	Bca	Brown (7.5*YR* 5/2) weakly bedded sandy silt loam. Structure: weak fine subangular blocky. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: moderately alkaline. Calcium carbonate mottling. Clear boundary.
	12–40	Cca	Light-brown (7.5*YR* 6/4) sandy gravel with local sand lenses. Structure: crudely bedded. Consistence: very friable. Reaction: moderately alkaline. Pebbles and cobbles have very thin coating or dendritic films of calcium carbonate. Diffuse boundary.
	40–70+	C	Light-brown (7.5*YR* 6/4) sandy gravel with local sand lenses. Structure: crudely bedded. Consistence: very friable. Reaction: neutral. No carbonate coatings.

A profile of the Brown soil facies developed on alluvial sand and silt of the Beaver Basin formation is given in section 22. A profile of the Brown soil facies developed on eolian sand and silt is given in section 27.

39. *Castle Creek soil, Sierozem facies*

[Relict profile on alluvial gravel of the upper member of the Beaver Basin formation composed mainly of diorite. Measured at altitude of 4,800 feet at edge of terrace along a tributary to Pack Creek northeast of Grand County airport in Spanish Valley (NW¼SE¼ sec. 36, T. 26 S., R. 22 E.). The vegetation is sagebrush]

Soil and associated rock unit	Depth (inches)	Horizon	Description
Castle Creek soil on alluvial gravel of upper member of Beaver Basin formation.	0–4	A	Weak-red (5*YR* 5/2) fine sand and silt. Structure: weak fine crumb. Consistence: nonsticky, nonplastic, loose. Reaction: moderately alkaline. Clear boundary.
	4–10	Bca	Reddish-brown (5*YR* 5/4) fine sand and gravel. Structureless. Consistence: loose. Reaction: moderately alkaline; partly leached calcareous coatings on some of the gravel. Gradual boundary.

39. *Castle Creek soil, Sierozem facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Castle Creek soil on alluvial gravel of upper member of Beaver Basin formation—Continued	10–50	Cca	Pink (7.5*YR* 7/4) sand and gravel. Structure: crudely bedded. Consistence: friable. Reaction: strongly alkaline. Gravel moderately coated with calcium carbonate; matrix of sand locally weakly cemented. Diffuse boundary.
	50–70+	C	Light reddish-brown (5*YR* 6/4) sand and gray gravel. Structure: crudely bedded. Consistence: loose to very friable. Reaction: neutral. No calcareous coatings.

40. *Castle Creek soil, Sierozem facies*

[Buried profile on alluvial sand and silt of the upper member of the Beaver Basin formation. Measured at altitude of 4,600 feet at type locality of Castle Creek soil in Castle Valley at the confluence of Castle Creek and Placer Creek (NW¼SW¼ sec. 8, T. 25 S., R. 23 E.). The alluvium of upper member of Beaver Basin formation overlies Pack Creek soil on alluvium of lower member and is overlain by alluvium of lower member of Gold Basin formation on which the Spanish Valley soil is developed (fig. 42). The vegetation is sagebrush]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Spanish Valley soil on alluvium of lower member of Gold Basin formation.	0–4	A	Reddish-gray (5*YR* 5/2) humic fine sandy silt loam. Structure: weak thin platy. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: moderately alkaline. Clear boundary.
	4–120	C	Light-reddish-brown (5*YR* 6/4) fine sand and silt with lenses of gravel. Structure: thin-bedded and crossbedded. Consistence: friable, soft. Reaction: moderately alkaline. Disconformity.
Castle Creek soil on alluvium of upper member of Beaver Basin formation.	120–130	A	Brown (7.5*YR* 5/2) humic fine sandy silt loam; darker in top 2 inches. Structure: moderate thin platy. Consistence: nonsticky, nonplastic, friable, soft. Reaction: moderately alkaline. Gastropods. Gradual boundary.
Castle Creek soil on alluvium of upper member of Beaver Basin formation—Con.	130–160	Cca	Light-reddish-brown (5*YR* 6/4) fine sand and silt. Structure: massive moderate coarse angular blocky. Consistence: nonsticky, nonplastic, friable, soft. Reaction: strongly alkaline; calcareous films along root holes and structural surfaces. A few gastropods. Clear boundary.
	160–270	C	Light-reddish-brown (5*YR* 6/4) to light-brown (7.5*YR* 6/4) sand and silt with local gravel lenses. Structure: thin-bedded and channel-bedded. Consistence: firm, hard. Reaction: moderately alkaline. Thin films of carbonate on bottoms of pebbles in gravel. A few fragments of charcoal. Abrupt disconformity.
Pack Creek soil on alluvium of lower member of Beaver Basin formation.	270–274	A	Gray-brown (10*YR* 5/2) humic sand and silt. Structureless. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: moderately alkaline. Gastropods. Gradual boundary.
	274–300	Cca	Light-reddish-brown (5*YR* 6/4) to light-brown (7.5*YR* 6/4) sand and gravel. Structure: thin-bedded. Consistence: firm, slightly hard. Reaction: moderately alkaline.
	300–330+	C	Light-brown (7.5*YR* 6/4) sand and gravel. Structure: thin-bedded. Consistence: friable, slightly hard. Reaction: mildly alkaline.

Another profile of the Sierozem facies of the Castle Creek soil on alluvial sand and silt of the upper member of the Beaver Basin formation is described in section 28.

41. *Castle Creek soil, Sierozem facies*

[Buried profile on eolian sand and silt of the Beaver Basin formation. Measured at an altitude of 4,500 feet in central part of Spanish Valley in a gully northwest of Summerville Ranch along gravel road that traverses length of the valley (SW¼ NW¼ sec. 19, T. 26 S., R. 22 E.). The upper 6 inches of section are deposits of upper member of Gold Basin formation that are being reworked at present. The vegetation is sagebrush]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Upper member Gold Basin formation.	0–6		Light-reddish-brown (5*YR* 6/4) loose eolian fine sand. Reaction: strongly alkaline. Abrupt boundary.
Castle Creek soil on eolian sand and silt of Beaver Basin formation.	6–10	A	Reddish-gray (5*YR* 5/2) humic fine sand. Structureless. Consistence: nonsticky, nonplastic, friable, slightly hard. Reaction: strongly alkaline. Gradual boundary.
	10–45	Cca	Pink (5*YR* 7/4) fine sand. Structure: eolian crossbedding. Consistence: friable, slightly hard. Reaction: strongly alkaline. Diffuse boundary.
	45–58	C	Light-reddish-brown (5*YR* 6/4) fine sand. Structure: eolian crossbedding. Consistence: very friable, soft. Reaction: mildly alkaline.

42. *Spanish Valley soil, Pedalfer facies*

[Relict profile on till of lower member of Gold Basin formation composed mainly of diorite. Measured on a moraine in north cirque of Beaver Basin, at altitude of about 11,300 feet (SE¼SW¼ sec. 13, T. 26 S., R. 24 E.). The vegetation is alpine tundra]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Spanish Valley soil on till of lower member of Gold Basin formation.	0–1	A	Very dark gray-brown (10*YR* 3/2) decayed tundra and stony sand. Structureless. Consistence: loose, except as held together by vegetation. Reaction: slightly acid. Gradual boundary.
	1–7	B	Dark-brown (10*YR* 4/3) sand, silt, and angular rock fragments. Structureless. Consistence: loose. Reaction: slightly acid. Gradual boundary.

42. *Spanish Valley soil, Pedalfer facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Spanish Valley soil on till of lower member of Gold Basin formation—Continued	7–16+	C	Yellowish-brown (10*YR* 5/4) coarse to fine sand, silt, and angular rock fragments (till). Structureless. Consistence: loose. Reaction: medium-acid.

43. *Spanish Valley soil, Pedalfer facies*

[Relict profile on eolian silt in interstices beneath surface of frost rubble of lower member of Gold Basin formation. Measured in a rubble sheet at altitude of about 10,800 feet on ridge at head of Schuman Gulch (SW¼NE¼ sec. 22, T. 26 S., R. 24 E.). The vegetation is sparse lichen]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Rubble sheet of lower member of Gold Basin formation.	0–12		Blocks of diorite from 6 to 12 inches in diameter, relatively unstable. Abrupt boundary.
Spanish Valley soil on eolian silt in interstices of rubble sheet.	12–14	A	Very dark gray-brown (10*YR* 3/2) humic silt containing decayed spruce needles, roots, and small twigs. Reaction: neutral. Clear boundary.
	14–20	B	Brown (7.5*YR* 5/3) silt in interstices of rock fragments. Structure: weak thin platy. Consistence: nonsticky, nonplastic, very friable, soft. Reaction: slightly acid. Gradual boundary
	20–36	C	Light-brown (7.5*YR* 5/4) silt and small rock fragments in interstices between large rock fragments. Structureless. Consistence: loose. Reaction: slightly acid. Abrupt disconformity; base of block field.
	36–44+		Yellowish-brown (10*YR* 5/4) sand, silt, and rock fragments; a solifluction mantle of the Beaver Basin formation. Structureless. Consistence: nonplastic, friable, slightly hard. Reaction: slightly acid.

44. *Spanish Valley soil, Pedocal facies*

[Relict profile on alluvial gravel of the lower member of the Gold Basin formation composed mainly of diorite. Measured at altitude of about 4,900 feet at a point due east of Grand County airport in scarp of a terrace about 6 feet above flood plain of tributary to Pack Creek that flows along east side of Spanish Valley (NW¼-NW¼ sec. 6, T. 27 S., R. 23 E.). The vegetation is sparse sagebrush and grass]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Spanish Valley soil on alluvial gravel of lower member of Gold Basin formation.	0–2	A	Brown (7.5*YR* 5/2) humic fine sand and silt. Structure: very fine crumb locally weak thin platy. Consistence: nonsticky, nonplastic, loose to very friable. Reaction: mildly alkaline. Clear boundary.
	2–70+	C	Light-brown (7.5*YR* 6/4) sandy gravel composed mostly of diorite. Structure: crudely bedded. Consistence: friable. Reaction: mildly alkaline. No obvious carbonate coating on the gravel.

Similar profiles showing little variation in the thickness of the A horizon were observed on gravel of the lower member of the Gold Basin formation along Pack Creek southeast of Spanish Valley and along Castle Creek in the central sector of Castle Valley.

45. *Spanish Valley soil, Pedocal facies*

[Buried profile on alluvial sand and silt of the lower member of the Gold Basin formation. Measured at altitude of about 4,550 feet at type locality of Spanish Valley soil in wall of an arroyo tributary to Pack Creek, about three-quarters of a mile downstream from dam in Spanish Valley (SE¼NE¼ sec. 22, T. 26 S., R. 22 E.) (fig. 53). The Spanish Valley soil is overlain by alluvial sand and silt of upper member of Gold Basin formation. The vegetation is sagebrush]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Modern soil on alluvium of upper member of Gold Basin formation.	0–1	A	Pinkish-gray (5*YR* 6/2) faintly humic sand and silt; weakly bedded. Structure: weak thin platy. Consistence: loose. Reaction: moderately alkaline. Clear boundary.
	1–40	C	Light-reddish-brown (5*YR* 6/4) sand and silt. Structure: massive to weakly bedded. Consistence: very friable, soft. Reaction: moderately alkaline. No visible carbonate. Abrupt disconformity.

45. *Spanish Valley soil, Pedocal facies*—Continued

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Spanish Valley soil on alluvium of lower member of Gold Basin formation.	40–56	A	Reddish-gray (5*YR* 5/2) humic sand and silt. Structureless to weak thin platy in upper few inches. Consistence: very friable, slightly hard. Reaction: moderately alkaline. Slight visible carbonate. Clear boundary.
	56–104	C	Light-reddish-brown (5*YR* 6/4) sand and silt. Structure: weakly bedded. Consistence: friable, soft. Reaction: moderately alkaline. Slight visible carbonate. Contains charcoal, hearths, points, and flaked chips. Abrupt disconformity.
	104–130+		Alluvial gravel of Beaver Basin formation.

The profile of the Spanish Valley soil on alluvial sand and silt is traceable in the wall of Pack Creek from the type locality downstream to the Colorado River. In this distance it varies only in the thickness and darkness of the humus horizon. In a few places it contains a little gypsum, suggestive of poor drainage at the time of origin. A few small gastropods and pelecypods were collected from both the A horizon and the underlying sand and silt. Other profiles of the Pedocal facies of the Spanish Valley soil developed on alluvial sand and silt are described in sections 28 and 40.

46. *Spanish Valley soil, Pedocal facies*

[Buried profile on eolian sand and silt of lower member of Gold Basin formation. Measured at altitude of about 5,800 feet at eastern edge of belt of inactive dunes along dirt road, known as Sand Flats road, that leads over the plateau east of Moab (SW¼SW¼ sec. 31, T. 25 S., R. 23 E.). These inactive dunes overlie Sierozem facies of Castle Creek soil on eolian sand of Beaver Basin formation and are enveloped by belts of active dunes of upper member of Gold Basin formation. The vegetation is blackbrush and sagebrush]

Soil and associated rock unit	*Depth (inches)*	*Horizon*	*Description*
Upper member Gold Basin formation.	0–6		Light-reddish-brown (5*YR* 6/4) eolian fine sand accumulating around vegetation. Loose and active. Abrupt disconformity.

46. *Spanish Valley soil, Pedocal facies*—Continued

Soil and associated rock unit	Depth (inches)	Horizon	Description
Spanish Valley soil on eolian sand of lower member of Gold Basin formation.	6–12	A	Reddish-gray (5*YR* 5/2) humic fine sand. Structure: faint eolian crossbedding. Consistence: very friable, soft. Reaction: mildly alkaline. Diffuse boundary.
	12–48	C	Light-reddish-brown (5*YR* 6/4) fine sand. Structure: eolian crossbedding. Consistence: very friable, soft. Reaction: mildly alkaline to neutral. Abrupt disconformity.
Castle Creek soil on eolian sand of Beaver Basin formation.	48–55	A	Dark-reddish-gray (5*YR* 4/2) humic fine sand. Structure: massive. Consistence: nonsticky, friable, slightly hard. Reaction: neutral. Gradual boundary.
	55–59	B	Reddish-brown (5*YR* 4/4) fine sand. Structure: massive. Consistence: slightly sticky, slightly plastic, friable, slightly hard. Reaction: neutral. Gradual boundary.
	59–77	Cca	Light-reddish-brown (5*YR* 6/4) fine sand. Structure: weak crossbedding. Consistence: nonsticky, nonplastic, friable, hard. Reaction: moderately alkaline. Visible calcium carbonate along structural planes and root casts.
	77+	C	Reddish-brown (5*YR* 4/4) fine sand. Compact, crossbedded, mildly alkaline. No visible calcium carbonate.

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