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along dissected terrain about 4 miles (6.4 km) east (fig. 1).

Step 1: Louviers Alluvium of South Boulder Creek
Locality: Borrow pit, SE ¼ NW ¼ sec. 9, T. 1 S., R. 70 W., Louisville quadrangle.

Description: Alluvial gravel about 14 feet thick, correlated with the Louviers Alluvium south of Denver

Broadway Alluvium, Piney Creek Alluvium, and modern alluvium.

Some features by which these surficial deposits are discriminated and correlated are mentioned in the following descriptions of localities visited on the field trip. The route proceeds southward from Boulder to Golden across upland pediments traversed by State Highway 93 and returns to Boulder via county roads along dissected terrain about 4 miles (6.4 km) east (fig. 1).

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TRIP 8

STRATIGRAPHY, SOILS, AND GEOMORPHOLOGY OF THE NONGLACIAL QUATERNARY DEPOSITS BETWEEN BOULDER AND GOLDEN, COLORADO

Harold E. Malde and Richard Van Horn

Along the east edge of the Rocky Mountain Front Range in Colorado several gravel-capped benches rise like giant steps from the valleys to a height of 400 feet (122 m) and abruptly intersect the mountain front, which rises steeply several thousand feet higher. These gravel deposits are produced by streams in Quaternary time on various tilted claystones and sandstones, mainly of Mesozoic age, which lie against Precambrian crystalline rocks in the mountains (Lovering and Goddard, 1950). This field trip between Boulder and Golden will examine these nonglacial Quaternary deposits and review some evidence from physiography, weathering, and fossils by which their ages have been inferred.

The Front Range began to rise at the end of the Mesozoic Era and since early Tertiary time this region has been progressively eroding. By Pliocene time, the eastern foothills of the mountains had been beveled by southeastward-flowing streams, which formed a broad upland erosion surface 2,000 feet (610 m) above the present mountain valleys, but considerably below the highest peaks of the range. This surface is still visible in the foothills as flat-topped summits at altitudes of about 8,000 feet (2438 m). Although no fossils have been discovered in alluvial debris preserved locally on this "subsummit" surface, physiographic relations suggest that it formerly was continuous with the base of the Pliocene Ogallala Formation on the High Plains, 100 miles (161 km) east. If so, the broad depression about 2,000 feet (610 m) deep between the foothills and the high Plains was carved out since deposition of the Ogallala. Most of this erosion was accomplished before gravel of Nebraskan or Aftonian age was deposited on the highest benches along the foothills. The amount of Pleistocene erosion is therefore comparatively minor. Nonetheless, the Pleistocene erosion surfaces and their associated surficial deposits comprise an interesting physiographic record, and they tell much about the latest history of the Front Range.

With the onset of the Pleistocene, streams draining the mountains, such as Boulder Creek, Coal Creek, and Clear Creek, were established in their present eastward courses, entrenched far below the subsummit surface. Owing to vicissitudes of Pleistocene climate prior to Wisconsin time, the rate of entrenchment was irregular, and streams along the mountain front periodically spread debris while cutting broad erosion surfaces. In this way, three pre-Wisconsin pediments (or terraces) mantled in turn by Rocky Flats Alluvium, Verdos Alluvium, and Slocum Alluvium were formed at progressively lower altitudes (Table I). Many geologists argue that such periods of later cutting, which presumably indicate temporary stability of streams heavily charged with debris, coincide with glacial episodes. Conversely, entrenchment of valleys below an erosion surface may be an attribute of interglacial conditions. Later, in Wisconsin and Recent times, after further dissection of narrow valleys below the upland pediments, several low alluvial terraces were built along the streams. From oldest to youngest these terrace deposits are named Louviers Alluvium,
VELoped. Although lacking conspicuous soil structure, the upper 2-3 feet (60-90 cm) of gravel is stained dark brown from secondary iron oxides, and the stones are coated with conspicuous clay skins. Some stones in the upper part are sparsely encrusted with thin films of calcium carbonate. Below the clayey layer the gravel to a depth of 5 feet (152 cm) effervesces with acid but is not noticeably calcareous. Rock fragments are almost entirely fresh, even those in the weathering profile, but a few pieces of gneiss and granite crumble easily in the hand. These evidently were reworked from older deposits. A few cobbles below a depth of 4 feet (122 cm) are fractured but are otherwise coherent.

This gravel probably is equivalent to the lower part of a gravel fill along the South Platte River at Denver (Hunt, 1954, p. 104-107). It represents outwash from Wisconsin glaciers in the Front Range (Madole, 1963).

Table 1. Sequence of alluvial deposits between Boulder and Golden.

<table>
<thead>
<tr>
<th>Alluvial deposits</th>
<th>Age</th>
<th>Maxi-Height</th>
<th>thickness</th>
<th>modern streams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modern alluvium</td>
<td>Christian era</td>
<td>5</td>
<td>0-5</td>
<td></td>
</tr>
<tr>
<td>Piney Creek Alluvium</td>
<td>Recent</td>
<td>12</td>
<td>5-10</td>
<td></td>
</tr>
<tr>
<td>Broadway Alluvium</td>
<td>Late Wisconsin</td>
<td>15</td>
<td>10-25</td>
<td></td>
</tr>
<tr>
<td>Louviers Alluvium</td>
<td>Early Wisconsin</td>
<td>40</td>
<td>10-70</td>
<td></td>
</tr>
<tr>
<td>Slocum Alluvium</td>
<td>Illinoian or Sangamon</td>
<td>15</td>
<td>90-125</td>
<td></td>
</tr>
<tr>
<td>Verdos Alluvium</td>
<td>Kansan or Yarmouth</td>
<td>40</td>
<td>170-200</td>
<td></td>
</tr>
<tr>
<td>Rocky Flats Alluvium</td>
<td>Nebraskan or Aftonian</td>
<td>50</td>
<td>350-400</td>
<td></td>
</tr>
<tr>
<td>Pre-Rocky Flats Alluvium</td>
<td>Pleistocene (?)</td>
<td>10</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Debris on subsummit surface</td>
<td>Pliocene</td>
<td>25</td>
<td>2,000</td>
<td></td>
</tr>
</tbody>
</table>

*1 ft. = 0.3048 m

Stop 2: Rocky Flats Alluvium

Locality: Canal, NE ¼ SW ¼ sec. 21, T. 2 S., R. 70 W., Golden quadrangle.

Description: Rocky Flats, a fluvial erosion surface veneered with bouldery gravel as much as 50 feet (15 m) thick, heads at the mouth of Coal Creek Canyon. It is the highest extensive alluvial gravel in the area, about 350-400 feet (107-122 m) above the modern valleys, but a higher remnant of still older gravel occurs on a knob about 40 feet (12 m) above Rocky Flats. Although the Rocky Flats Alluvium is dominated by pebbles and cobbles, it contains numerous boulders as large as 2 feet (60 cm). It consists of 60 percent quartzite, 20 percent schist and gneiss, 12 percent granite, and 8 percent sandstone. One of these, a weakly calcareous facies characteristic of places on Rocky Flats near the mountains, has been strongly weathered. Quartzite pieces have a stained and crumbly rind 2-5 mm thick. Granite and gneissic fragments are decomposed, and their outlines are commonly obscured by secondary clay. The weathering profile has two facies. One of these, a weakly calcareous facies of paleosols in this region believed to be of pre-Wisconsin age (Hunt and Sokoloff, 1950). The Rocky Flats Alluvium is considered to be Nebraskan or Aftonian in age (Scott, 1960) because of its physiographic relation to the next lower alluvial gravel, the Verdos Alluvium, which is late Kansan or Yarmouth.

Stop 3: Alluvial deposits along Ralston Creek

Locality: Valley rim, SE ¼ SE ¼ sec. 33, T. 2 S., R. 70 W., Golden quadrangle.

Soil profile on Rocky Flats Alluvium

<table>
<thead>
<tr>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger soil</td>
<td>(feet) (cm)</td>
</tr>
<tr>
<td>1. Stony loam, dark-brown (7.5 YR 3/2)</td>
<td>0.2 6</td>
</tr>
<tr>
<td>2. Stony clay loam, dark-brown; medium subangular blocky structure</td>
<td>0.6 18</td>
</tr>
<tr>
<td>Pre-Wisconsin soil</td>
<td></td>
</tr>
<tr>
<td>3. Stony clay, reddish-brown (2.5 Y 4/4); angular blocky structure, locally prismatic</td>
<td>2.2 67</td>
</tr>
<tr>
<td>4. Stony loam, yellowish-red (5 YR 4/8); noncalcareous</td>
<td>1.5 46</td>
</tr>
<tr>
<td>5. Gravel, mainly quartzite, impregnated with dense calcium carbonate (caliche)</td>
<td>3+ 91+</td>
</tr>
</tbody>
</table>

The indurated caliche and the overlying clay in this profile are typical of paleosols in this region believed to be of pre-Wisconsin age (Hunt and Sokoloff, 1950). The Rocky Flats Alluvium is considered to be Nebraskan or Aftonian in age (Scott, 1960) because of its physiographic relation to the next lower alluvial gravel, the Verdos Alluvium, which is late Kansan or Yarmouth.

Stop 4: Volcanic ash in Verdos Alluvium at Golden

Locality: Ditch, NE ¼ SW ¼ sec. 26, T. 3 S., R. 70 W., Golden quadrangle.

Description: A lens of bedded volcanic ash 1 foot (30 cm) thick, which has chemical and petrographic similarities to the Kansas Pearlette Ash of Frye, Swineford, and Leonard.
(1948; see also Powers, Young, and Barnett, 1958), occurs 2 feet (60 cm) above the base of Verdis Alluvium deposited by ancient Clear Creek. The Verdis at this locality consists of cobbly gravel dominated by granite and metamorphic rocks, and its remnants define a terrace 170 feet (52 m) above Clear Creek. On a hill ½ mile (0.8 km) northeast, where the ash is also present, the gravel reaches a thickness of 40 feet (12 m). A short distance to the west, gravel below the ash includes boulders as large as 3 feet (90 cm).

This volcanic ash is thought to be equivalent to ash mentioned by Hunt (1954, p. 96-97) in gravel 200 feet (61 m) above Bear Creek, and 250 feet (76 m) above the South Platte River, southwest of Denver. Similar volcanic ash also occurs in Verdis Alluvium north ofRalston Creek (about a mile northwest of Stop 3). Other outcrops of Verdis Alluvium that contain volcanic ash with similarities to the Pearlette are described by Scott (1963a, p. 17-18).

The Pearlette Ash of Frye, Swineford, and Leonard (1948) is widely distributed in the central Great Plains. In Nebraska it occurs in the Sappa Formation, which yields vertebrate and molluscan fossils indicating late Kansan or early Yarmouth age (Miller and others, in press). In southwest Kansas, at the type locality, Hibbard (1938) placed the Pearlette in the Atwater Member of the Crooked Creek Formation and assigned a Late Kansan age on the basis of vertebrate and molluscan fossils.

Stop 5: Louviers Alluvium along Clear Creek

**Locality:** Borrow pit, NW ¼ SE ¼ sec. 19, T. 3 S., R. 69 W., Golden quadrangle.

**Description:** Louviers Alluvium about 40 feet (12 m) thick, consisting dominantly of coarse rounded pebbles of granite and metamorphic rocks, forms a terrace half a mile (0.8 km) wide 50 feet (15 m) above Clear Creek. The alluvium is well developed and at this place displays polygenetic features. A dark topsoil 4 inches (10 cm) thick, normally the A horizon, has developed on an older B horizon, as indicated by clay skins on soil peds. The entire B horizon, a reddish-brown zone characterized by secondary iron oxide and clay, is ½ feet (45 cm) thick. It is underlain by 3 feet (90 cm) of gravelly subsoil sparsely enriched with secondary calcium carbonate.

Many vertebrate fossils are reported by Scott (1963a, p. 33) from Louviers Alluvium south of Denver, notably Bison antiquus and Mammutthus (Paralephas) columbi of Wisconsin age. Scott also lists 39 species of molluscan fossils from the Louviers, most of which are land snails that prefer a cool dry habitat. They were evidently carried into the alluvium after death. On the basis of these fossils, the Louviers Alluvium is considered to be of early Wisconsin age.

**Stop 6: Broadway Alluvium in upland valley**

**Locality:** Boundary road, SE ¼ SE ¼ sec. 19, T. 2 S., R. 69 W., Golden quadrangle.

**Description:** Broadway Alluvium consisting of sandy silt more than 10 feet (3 m) thick forms a narrow terrace 25 feet (8 m) above a small upland stream that flows between banks of Piney Creek Alluvium. This terrace lies 35 feet below a ridge to the north built of Louviers Alluvium.

The weathering profile is moderately well developed. Below a few inches of sandy colluvium, a dark grayish-brown prismatic zone less than a foot thick is clayey and non-calcareous. Secondary calcium carbonate in the form of sparse veinlets on joint facies is found in the subsoil to a depth of about 3 feet (90 cm). This profile resembles the soil of early Recent age south of Denver described by Scott (1963a, p. 41).

**Stop 7: Piney Creek Alluvium**

**Locality:** Arroyo, SE ¼ NW ¼ sec. 31, T. 1 S., R. 69 W., Louisville quadrangle.

**Description:** Fine-grained Piney Creek Alluvium generally more than 10 feet (3 m) thick forms the floor of many upland valleys, such as this one, as well as the bottomland along the larger streams. In upland valleys the surface of the alluvium is remarkably flat and ends abruptly at the valley walls. The Piney Creek Alluvium is typically dark gray and mostly ranges in texture from silty sand to clayey silt, but gravel lenses are common in the lower part. Abundant interstratified humic layers mark the places where the larger streams have been incorporated in some upland valleys.

The Piney Creek Alluvium is nearly everywhere incised by a steep-walled arroyo.

The Piney Creek Alluvium has a weakly developed soil characterized by a grayish-brown A horizon less than a foot thick underlain by a thin zone containing sparse veinlets of calcium carbonate.

Remains of Bison bison are locally abundant in the Piney Creek, as at this locality, and a few stone artifacts (Hunt, 1953, p. 7) have also been found. The Piney Creek Alluvium is dated as Recent, on the basis of these remains, and from its relation to other deposits.

**Stop 8: Loess of Wisconsin age**

**Locality:** Ditch, center NE ¼ sec. 6, T. 1 S., R. 69 W., Louisville quadrangle.

**Description:** A widespread deposit of massive elolian silt and sand more than 10 feet (3 m) thick forms a smooth mantle on rolling topography a few miles from the mountain front. The loess is mostly fine sand, but a few fine pebbles and lenses of coarse sand have been incorporated in some places by slopewash from gravely

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**Soil Profile on Wisconsin loess**

**Younger soil:**
- Loam, sandy, grayish-brown or brown, noncalcareous
- Unconformable on layers below

**Wisconsin soil:**
- B horizon-Clay, compact; prismatic structure. Dark-brown to reddish-brown and noncalcareous in upper part; grayish-brown and moderately calcareous in lower part
- C horizon-Clay loam, gray, friable; jointed structure. Highly calcareous with calcium carbonate films along vertical joints
- Parent material-Fine sandy loam, light-brown, friable, calcareous
areas upslope. A few pebbles are scoured and polished by wind abra-
sion.

The loess has a well-developed weathering profile, which is exposed at this locality (Malde, 1955, p. 241-242). The profile is briefly described on page 45.

At this locality, the Wisconsin loess rests on structureless sand contain- ing remnants of a pre-Wisconsin paleosol (Malde, 1955, fig. 55). The contact can be traced southward along the ditch onto the slope that skirts Davidson Mesa, where underlying Cretaceous claystone is ex-
posed.

Fossil land snails that suggest cold dry conditions have been collected from loess deposits on Louviers Alluvium south of Denver. On the basis of this fauna the loess is considered to be early Wisconsin. It is correlated with the Peorian Loess in Nebraska.

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