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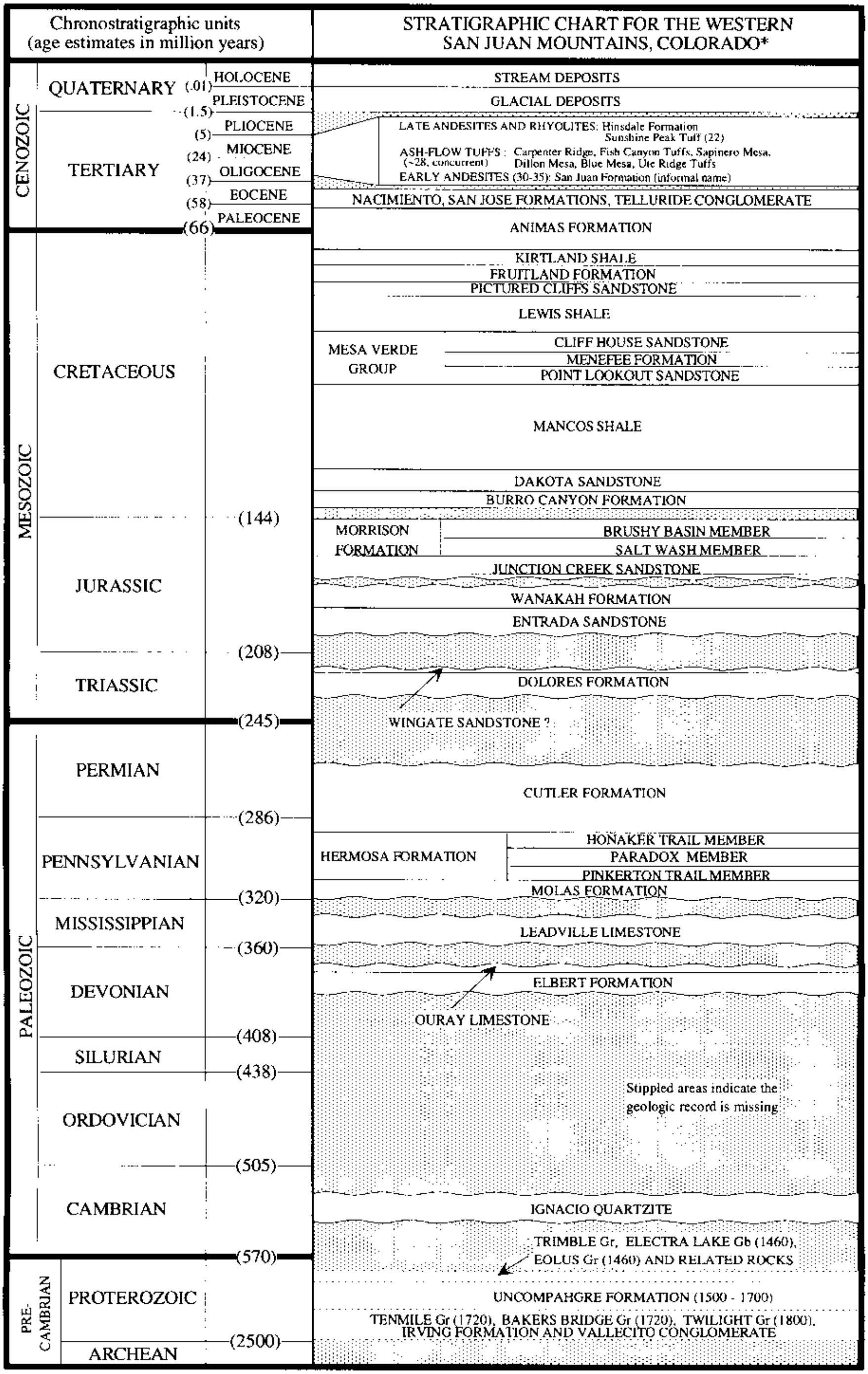

Modified after MacLachlan 1981.

CHAPTER 1

ORIGIN OF LANDSCAPES

ROB BLAIR

The San Juan Skyway, a 235-mile highway loop in southwestern Colorado, winds its way up, over, and through canyons, mesas, plateaus, mountains, plains, and valleys. The sheer variety of landforms makes the Skyway a veritable classroom for the student of geomorphology. One explanation for the large diversity of landscapes on this route is that the Skyway straddles two major physiographic provinces, the Southern Rocky Mountains and the Colorado Plateau (Fig. 1.1). Each of these regions contains a unique suite of landforms and structures.

The Southern Rocky Mountains province dominates the Skyway loop and is represented specifically by the San Juan mountain range. Regionally, the province is associated with anticlinal arches, intervening basins, and glaciated mountains, all at alpine and subalpine altitudes (Pirkle and Yoho 1985). The Front Range is an example of an eroded anticlinal arch; South Park and the San Luis Valley are intervening basins; and the San Juan Mountains constitute one of many glaciated ranges.

The Colorado Plateau province lies within the four states of Utah, Colorado, Arizona, and New Mexico. The southwestern portion of the Skyway falls mostly within the Navajo section of the Colorado Plateau and partly within the Canyonlands section. Geologically, the plateau can be described as a large elevated block consisting of several thousand feet of Paleozoic and Mesozoic sedimentary rock (Thornbury 1965). The horizontal to gently dipping strata are disrupted in places by laccolithic mountains

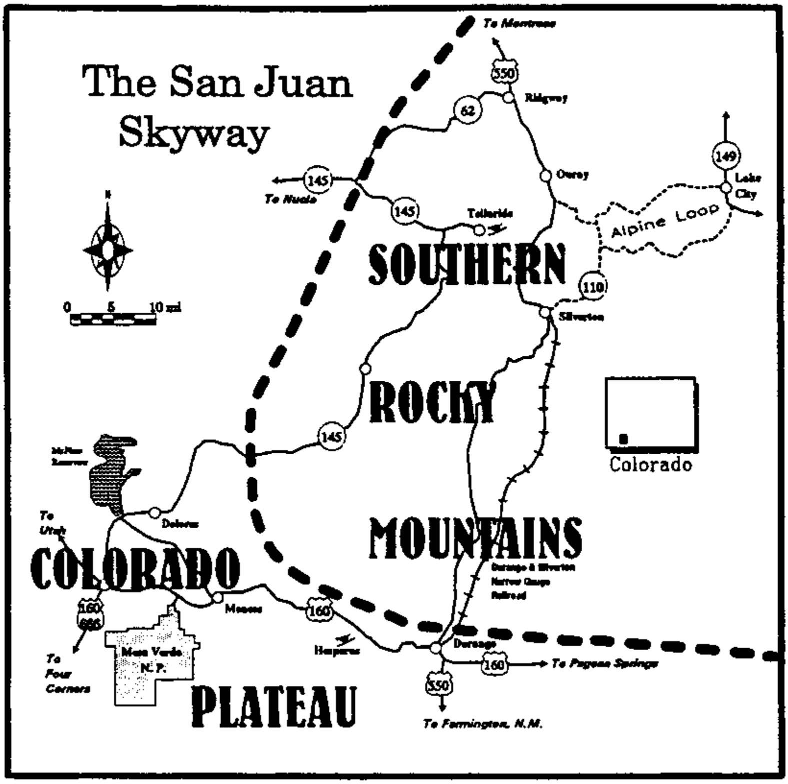

Fig. 1.1 Generalized boundary of Colorado Plateau and Southern Rocky Mountain provinces across the San Juan Skyway.

(Sleeping Ute Mountains, Cortez), monoclines (Hogback Monocline, Durango), upwarps (Monument Upwarp, Utah-Arizona border), basins (San Juan Basin, northwestern New Mexico), collapsed salt anticlines (Paradox Valley, Colorado), and faults (House Creek Fault, Dolores). Centers of volcanic activity mark much of the plateau perimeter. The region, however, is most noted for its colorful canyons and mesas.

The boundary between the Colorado Plateau and the Southern Rocky Mountains is broadly defined as the zone in which sedimentary formations rise onto the uplift of the San Juan Mountains (Hunt 1956).

LANDSCAPE ORIGIN

Geologic processes can be classified as either endogenic or exogenic. Endogenic processes are those that are generated underground and include mountain building and volcanic activity. Exogenic processes are those that occur upon the earth's surface and are represented principally by weathering and erosion. The endogenic and exogenic processes act simultaneously to reshape the surface.

At this boundary between the earth's crust and atmosphere, there is an exchange of energy and movement of materials that creates "interference" patterns. We call these patterns *landforms*, which collectively produce *landscapes*. A simple interference pattern results when wind blows across water to form wave trains or over sandy regions to form sand dunes. In these instances the wind is the energy driver, and the surface medium is homogeneous. However, when a system consists of multiple energy drivers such as running water, glaciers, and tectonic uplift and a variety of rocks (some soft, some hard, some shattered), then the landscapes become incredibly complex. Moreover, the landforms change and evolve through time. Such is the situation around the San Juan Skyway.

LANDSCAPE FACTORS

Several key factors often have great influence in shaping a region's geomorphology. In my view, seven main factors have helped create the Skyway landscape. These seven are not of equal importance, nor do they represent all influences on the evolving landscape. The factors are:

1. the presence of hard, resistant igneous and metamorphic rocks
2. the presence of alternating soft and hard sedimentary strata
3. episodic uplift and deformation
4. late Cretaceous plutonic activity
5. late Tertiary volcanic activity
6. multiple glaciations
7. postglacial processes

HARD "BASEMENT" ROCKS

To anyone who has flown over the San Juan Mountains, their most striking features are the jagged, sharp-pointed peaks jutting into the air. With few exceptions, the most spectacular of these peaks consist of resistant rock. For example, seven 14,000-foot-high (4,267 m) peaks in the immediate vicinity of the Skyway are composed of hard igneous plutonic rock. Mount Eolus, Mount Windom, and Sunlight Peak in the Needle Mountains are composed of Eolus Granite (Cross, Howe et al. 1905). El Diente, Mount Wilson, and Wilson Peak in the San Miguel Mountains are carved from granodiorite associated with the Wilson Peak stock (Bromfield and Conroy 1963), and Mount Sneffels, west of Ouray, is made up of granodiorite-related rocks (Tweto et al. 1976). North of the Needle Mountains stands the spectacular Grenadier Range, composed of hard quartzites of the Uncompahgre Formation. Vestal, Arrow, and Garfield Peaks were hewn from these quartzites, perhaps the hardest of all naturally occurring rocks.

VARIABLE HARDNESS OF SEDIMENTARY STRATA

The distinct layered look of sedimentary rock comes about because of successive episodes of deposition. The layers show up as differences in color, texture, and hardness. Topography reflects variable hardness in particular, because the resistant layers form cliffs, whereas the softer layers break down to form slopes or hollows beneath cliffs. For example, the prominent cliff-forming layers in the upper Animas Valley include the Leadville-Ouray Limestone and the Hermosa Formation (see Stratigraphic Chart, p. 2). The Junction Creek Sandstone forms a popular rock-climbing cliff just north of Durango, and the Dakota Sandstone caps Animas City Mountain at Durango and the valley walls around the town of Dolores. Mesa Verde would not exist as a plateau if it were not for the Point Lookout and Cliff House Sandstones.

Two common slope-forming layers are the Morrison Formation and the Mancos Shale. Slopes below the Dakota Sandstone just north of Durango and around Dolores comprise the Morrison Formation. The prominent gray slopes below the cliffs around Mesa Verde National Park are composed of Mancos Shale. These slope-forming units are made up of mudstones and shales, which weather rapidly because their binding cement is not strong.

EPISODIC UPLIFT

Uplift and deformation have occurred episodically throughout the geologic history of the San Juans and are responsible for the tilting of sedimentary strata, faulting, erosion surfaces, and the uplift of mountains. The approximately 15,000 feet (4,550 m) of Phanerozoic strata found in the vicinity of Durango (Lee et al. 1976, Fig. 3, p. 144; Baars and Ellingson 1984, Fig. 7, p. 12) record at least eleven erosion events. These episodes are preserved as unconformities (note the wavy lines in the Stratigraphic Chart, p. 2), four of which are known to record local uplift in the early Cambrian, Permian, late Cretaceous, and late Tertiary. The last two events together produced the tilting of sedimentary strata that form a cuesta at Mesa Verde and hogbacks at Durango.

Deformation has buckled and broken the earth's upper crust to create fracture zones and fault blocks. The uplifted Grenadier and Mount Sneffels horst blocks of hard Precambrian quartzites, for example, form the backbone of the western San Juan Mountains. These blocks are bounded by faults that have shifted several times since the Precambrian (Baars and Ellingson 1984). Erosion frequently occurs along fracture zones to create stream valleys or prominent escarpments. Examples include Mineral Creek, which closely follows the ring fractures west of Silverton associated with the Silverton Caldera. The steep slopes immediately south of Ouray are partly the result of the east-west-trending Ouray Fault.

LATE CRETACEOUS PLUTONIC ACTIVITY

Along the western perimeter of the San Juan Mountains stand four structural domes created by the intrusion of mushroom-shaped plutons called laccoliths. These domes include the La Plata, Rico, San Miguel, and Sleeping Ute Mountains. The La Plata Mountains, for instance, formed from multiple intrusions of magma from a point source some 65 million to 67 million years ago (Cunningham et al. 1977). The magma invaded the near-surface sedimentary layers to produce a complex of dikes, sills, and laccoliths. These laccolithic mountains differ from the central San Juans principally because they eroded from a complex of interfingering plutons and sedimentary layers, whereas the San Juans eroded from a thick volcanic pile resting upon an eroded Precambrian crystalline basement.

LATE TERTIARY VOLCANIC ACTIVITY

The rocks in the San Juans record an unusual period of tectonic stability in early Tertiary time, about 40 million years ago. This crustal quiescence is revealed by a buried erosion surface found throughout much of the western San Juan Mountains and forms an angular unconformity beneath the Telluride Conglomerate, a cliff-forming unit exposed from Molas Pass to Telluride. The overlying rocks mark the beginning of vigorous uplift in the central and eastern San Juans that culminated in some of the most violent volcanic activity ever recorded on the planet.

Between 30 and 35 million years ago, large stratovolcanoes were built upon remnants of the erosion surface and created a broad volcanic plateau (Steven 1975). These stratovolcanoes probably looked much like today's Mount Rainier. This early stage of volcanism is recorded by the presence of the San Juan Formation, a mixture of andesitic flows, breccias, and intermediate volcaniclastic deposits. However, beginning around 29 million years ago the style of volcanic activity changed. Some of the stratovolcanoes were destroyed by sticky, high-pressure felsic magma that burst through ring fractures and vents to blast hundreds to thousands of cubic kilometers of volcanic ash into the atmosphere (Steven and Lipman 1976). The ejected magma emptied the holding chamber beneath the surface, causing the overlying crust to collapse into the void, creating a caldera. The expelled ash was then deposited as a thick blanket over the existing landscape. This sequence of events happened not once but at least fifteen times over various parts of the San Juan Mountains during a 7-million-year period. The northern Skyway area preserves a known record of four of these eruptions (see Chapter 6).

The mountains carved from these ash-flow tuffs, flows, and volcanic breccias have a number of general characteristics that set them apart from the plutonic mountains discussed earlier. The volcanic rock is brittle and fractures easily into angular fist- and head-sized chunks from hydration and freeze-thaw weathering processes.

Thus, summits appear as piles of rubble. Examples include the Red Mountains north of Red Mountain Pass. These summits are usually not as high as the plutonic rock summits seen in the Needle Mountains and elsewhere around the Skyway.

Some volcanic flow units and shallow intrusive rocks display vertical cooling cracks or columnar joints. Such features appear in the rocks exposed in Hendrick Gulch in north Ironton Park and in the summit rocks of Engineer Mountain, west of Coal Bank Hill. Because the volcanic rock breaks down so readily, there is an abundant supply of rock fragments to cascade down cliffs and slopes to form large talus cones, debris fans, and rock glaciers.

MULTIPLE GLACIATIONS

Perhaps no other erosional agent has left its mark on this landscape more than glaciation. It is principally responsible for the deep, U-shaped canyons and steep-walled mountain peaks seen around the Skyway (Fig. 1.2). This glacial signature was etched on a scattered late Pliocene erosion surface that truncated the

Fig. 1.2 Looking south from Dallas Divide. View shows glacial cirques, horns, and arêtes in the Sneffels Range. Photo by R. Blair.

Precambrian crystalline rocks and the late Tertiary volcanic rocks (Atwood and Mather 1932; Steven 1968).

The San Juan Mountains may have experienced fifteen or more glacial advances in the last 2 million years, but only six of these are recorded by glacial deposits. The evidence of the earlier glaciations has been destroyed by the more recent ones and by erosion between glacial advances. Therefore, we cannot say when the region first became a refuge for glacial ice. However, we do know approximately when the glaciers disappeared. According to carbon-14 dating of organic sediments found in alpine bogs and lake sediments (Maher 1972, Carrara et al. 1984), the high glacial cirques in the San Juans were ice-free at least 15,000 years ago. Tree-ring data and Antarctic ice cores indicate that the planet experienced a glacial maximum some 18,000 years ago (Skinner and Porter 1987). The San Juans record this event with glacial deposits at the north edge of Durango and north of Ridgway. Thus, deglaciation must have taken place between 18,000 and 15,000 years ago.

For glaciers to grow, ice accumulation rates must be greater than ice ablation, or wastage, rates. The boundary between the ablation zone and the overlying accumulation zone is called the Equilibrium Line Altitude, or ELA, and corresponds roughly with the permanent snowline found in the highest mountain ranges. The ELA today lies between 12,200 and 12,300 feet (3,725–3,750 m) in the Grenadier Range (Leonard 1984). Only the highest peaks pierce this imaginary surface. The ELA varies from place to place because of local differences in topography, precipitation, and temperature. During the last global cooling, 18,000 years ago, the ELA dropped between 1,000 and 2,000 feet (300–600 m) and, in so doing, turned the huge upland surface of the San Juans into a dumping ground for snow and ice. The ice grew rapidly in thickness and finally into full-fledged glaciers.

The San Juan Mountains, during each maximum glacial episode, were covered with an ice-field complex covering about 1,900 square miles (5,000 sq km) (Atwood and Mather 1932). The ice field consisted of a thin layer of ice over the high divides and uplands, with streams of ice radiating out into river valleys like the arms of an octopus (Fig. 1.3). Some of the high peaks, such as Engineer, Sultan, Pigeon, and Turret, rose above the ice field, forming

Fig. 1.3 The distribution and flow directions of glacial ice approximately 18,000 years ago in the San Juan Mountains, as inferred by Atwood and Mather (1932). Black squares indicate radiocarbon sites (from Carrara et al. 1984).

rock islands called nunataks by glaciologists. The tree line is estimated to have dropped by 2,100 feet (650 m) during these times (Maher 1961), and, of course, the valleys filled with ice were devoid of vegetation. The Animas glacier was one of the longest valley glaciers in the Southern Rocky Mountains. It extended for more than 40 miles (65 km) from Silverton to Durango. Once deglaciation commenced, the ELA rose above the San Juan "plateau," and the glaciers disappeared rapidly, leaving only a few small glaciers in north-facing cirques (Carrara et al. 1984). Glacial erosion, however, left its mark throughout the San Juan Mountains in the form of horns, cirques, hanging valleys, arêtes, and numerous U-shaped valleys.

In addition to causing erosion, the glaciers left deposits of lateral and end moraines. Lateral moraines line parts of both sides of the Animas Valley, and the best-developed end moraines are found at Durango and Ridgway. When the ice left the Animas and Uncompahgre Valleys, it left deep, U-shaped troughs that initially filled with water to form large proglacial lakes. The lakes quickly accumulated sediment and glacial outwash to form the flat-floored valleys seen today.

POSTGLACIAL PROCESSES

After each glaciation, the ongoing processes of stream erosion, mass wasting, and freeze-thaw modified the glaciated landscape. In particular, rivers cut deep canyons and built flights of terraces. River terraces reflect a complex response to major changes in the hydraulic flow of the river (Schumm 1977). Such changes may come about because of floods, sudden changes in gradient due to uplift or subsidence, channel blockage, or changes in climate. The majority of the well-developed river terraces in the Four Corners region represent the effects of multiple glaciations, where rivers were subjected over thousands of years to changes in discharge and sediment load. When the glaciers began their retreat, the valley floors were choked with sediment, which was being continuously reworked by braided streams across a broad floodplain. When discharges dropped, single channels formed and slowly carved into bedrock, leaving portions of the abandoned floodplain high and dry. The best terraces can be seen south of Durango (Fig. 1.4), but nearly every river has a few (Gillam et al. 1984).

The most common mass-wasting processes encountered around the Skyway drive are landslides, mudflows, debris flows, and creep. Landslides, for example, have continually modified the

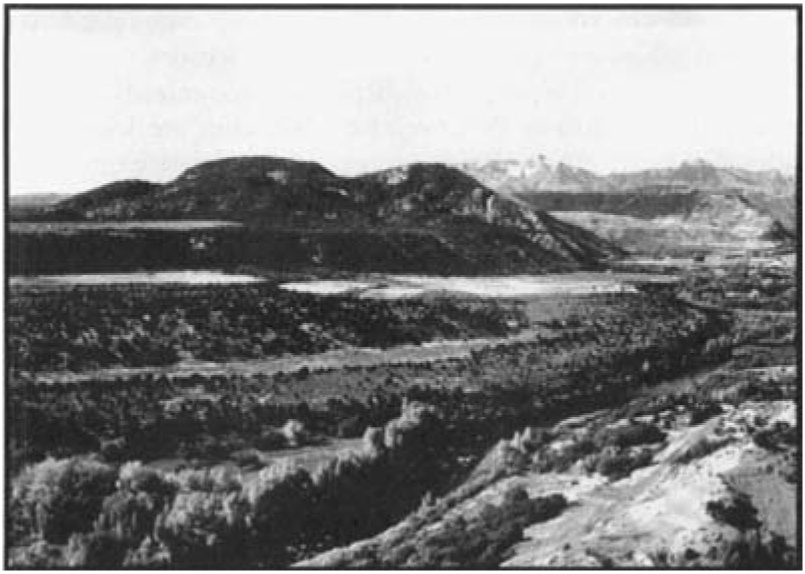

Fig. 1.4 Looking northwest at Animas River terraces 4 miles south of Durango. Photo by R. Blair.

steep shale slopes and even the highway between Mancos and Hesperus. A mudflow threatened the Telluride airport in the spring of 1987. Debris flows tend to be rare events, but their deposits can be seen at the north end of Ironton Park and at the base of nearly every avalanche chute. Soil creep can be recognized by the continuous curve of trees from trunk to tip. The basal curve noted in many trees, however, especially aspen, is caused by snow creep in winter during the first few years of tree growth.

Snow avalanches are also considered a mass-wasting phenomenon. Snow avalanches have accounted for 264 deaths in the San Juan Mountains between 1874 and 1991 (Dale Atkins 1991, personal communication), and thus they live up to their nickname, "white death." Most of these accidents occurred during the early boom days of mining, but even today hardly a year goes by that some unwary skier does not lose his or her life. The steep, treeless alleyways down gullies and slopes are avalanche paths. Whether an avalanche runs or not depends on the topography, nature of the snow, and local climatic conditions (Perla and Martinelli 1976).

Some avalanche zones run several times a year, some only once a year, and others perhaps only once in several decades.

Two general types of avalanches are recognized, point release and slab release. Point-release avalanches are loose-snow slides that begin from a point and spread out quickly into a fan-shaped flow. They are most common in the early winter and usually occur within forty-eight hours after a major snowstorm. The East Riverside slide in the upper Uncompahgre Canyon runs after virtually every major snowstorm. Slab-release avalanches have the potential to do the most damage because their release time is less predictable and because they can involve huge volumes of snow. They are more common in late winter and early spring. On March 3, 1963, the Reverend R. F. Miller and his two daughters were swept to their deaths by a large slab avalanche that bolted across U.S. 550 at the East Riverside slide, 5 miles south of Ouray (Gallagher 1967).

Freeze-thaw processes have left their signature, mostly above timberline, in the form of shattered rock, stone stripes and rings, flowing lobes of soil, and rock glaciers. Rock glaciers are lobate or tongue-shaped masses of angular rocks that can flow downslope at rates of several inches per year. Talus from rockfall is the most common source of debris, so most rock glaciers are found adjacent to cirque headwalls or cliffs. Rock glaciers have commonly been classified as either being ice-cored or ice-cemented (White 1976). The former are thought to have a solid core of ice perhaps tens of feet thick. In some instances this may be relict ice left over from a previous glacier. These rock glaciers are tongue-shaped and can exhibit meandering longitudinal furrows on their surface. Compression ridges commonly appear near their snouts. Ice-cemented rock glaciers are composed of angular rocks bound together by interstitial ice, and they can also exhibit a flowage signature.

More than 650 rock glaciers have been recognized in the San Juan Mountains (White 1979). This region has perhaps the largest concentration of this kind of feature in the conterminous United States. Of these rock glaciers, approximately 61 percent are actively moving, 28 percent are tongue-shaped, but only 6 percent are thought to be ice-cored (White 1979). Rock glaciers and other

Fig. 1.5 Looking northwest at the Imogene Basin rock glacier. U.S. Geological Survey photo by A. C. Spencer and E. Howe 1899.

freeze-thaw phenomena can be seen at the base of Mount Snowdon southeast of Molas Pass and above timberline along the Ophir Pass and Imogene Pass four-wheel-drive roads (Fig. 1.5).

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