In 1910, a remote area in northwestern Montana was recognized for its spectacular scenery, rugged terrain, and pristine ecosystem. With the dedication of 1.4 million acres, this area became Glacier National Park, named after the dynamic forces that sculpted its landscape. Bordering the Canadian provinces of Alberta and British Columbia, Glacier National Park encompasses forests, alpine meadows, lakes, and glaciers.

The park provides an outstanding classroom for naturalists and terrain modelers. The many valleys, carved by alpine glaciers, dissect the landscape and create a terrain modeling wonderland.

The park also presents many modeling challenges. Located just below the United States-Canadian border, it is immediately south of the 49th parallel and straddles the boundary between Universal Transverse Mercator (UTM) Zones 11 and 12. Its location is at the far west end of the Montana State Plane NAD83 Single Zone. In both UTM and State Plane, conic projection parameters rotate the model of Glacier National Park significantly.

About Glacier National Park

Take a virtual GIS field trip through a portion of Glacier National Park in northwestern Montana. Observe young glacial geomorphology and old rocks in the Quartz Lake/Rainbow Peak area of Glacier National Park.

Visit ArcUser Online to download an archived file that contains a published map file (PMF) of the model referenced in this virtual hike. Because this is a PMF document, it can be viewed using the free viewer, ArcReader, available at www.esri.com/arcreader. This file can also be viewed in ArcMap at any license level and does not require any extensions. After downloading and extracting the files from the archive, open fieldtrip.pmf.

Several interactive features have been included with this map.

- Use the bookmarks to quickly zoom to the stops along the virtual hike. From the Standard menu, choose View > Bookmarks, then choose the bookmark for the stop of interest.
- Map tips have been enabled for the geomorphic features, surficial geology, and bedrock geology layers. Pausing the cursor over these features will bring up identifying information. Look up any unfamiliar geologic terms in the accompanying glossary.

Extensive alpine glaciers carved rocks as old as 1.4 billion years and created a rugged terrain of sharp peaks, steep cliffs, and flat valley floors that can be seen throughout Glacier National Park. Remnants of these Pleistocene Age glaciers were active only 15,000 years ago and remain at higher elevations in the park.

Virtual Geomorphology

By Mike Price, Entrada/San Juan, Inc.
Stop 1—Cruising Quartz Lake
(elevation 1,347 meters)
Our trip starts with a 6.5-kilometer canoe trip up Quartz Lake, a narrow water body impounded by landslide debris. Quartz Lake is one of several large lakes that have formed in the flat bottoms of U-shaped valleys carved by Pleistocene glaciers. Terminal moraines and rockfall combine to create natural dams for these long, narrow lakes. As we travel up the lake, observe the steep valley walls and hanging valleys high above cascading waterfalls.

Stop 2—An Alluvial Fan
(elevation 1,347 meters)
A small unnamed drainage has deposited rock material at the point where it enters Quartz Lake. A mix of different rock types has tumbled from cliffs above. Look north toward the hanging valley and observe the truncated spurs on each side.

Stop 3—A U-Shaped Valley
(elevation 1,348 meters)
At the upper end of Quartz Lake, we dock our
canoe and begin hiking. Look back down the valley and observe its U-shaped form. Valley glaciers typically erode steep canyon walls while flattening the valley floor. Stream erosion formed a V-shaped valley typified by a uniform slope.

Stop 4—Glacial Till
(elevation 1,362 meters)
We are hiking across brushy glacial till that was left behind when the Pleistocene glacier that filled this valley melted 10,000 years ago. Notice the irregular, or hummocky, landform. Glaciers are not picky when it comes to the size of material transported. When the ice melted, large irregular rocks were deposited along with sand and silt. Over time, water has moved some of the finer material but left the large rocks behind.

Stop 5—Cerulean Lake—A Tarn in Glacial Cirque (elevation 1,430 meters)
We cross a small divide and enter the cirque basin containing Cerulean Lake. Located in a depression formed by glacial scouring, this lake is a tarn. Observe the symmetric concave valley form. This concave form is called a cirque. Imagine how this valley might have looked when filled with nearly 1,000 meters of ice.

Stop 6—The Cirque Headwall
(elevation 1,438 meters)
We hike away from the lake and along a truncated spur. The headwall of this cirque is very steep. We climb the south facing slope of the neighboring hanging valley before reaching a knife-edged ridge, or arête.

Stop 7—Valley Viewpoint, Appekunny Formation (1.2–1.4 billion years)
(elevation 1,660 meters)
This is a great place to stop and become acquainted with the bedrock geology in the Quartz Lake area. We are surrounded by hard sedimentary rocks of the Belt Supergroup. Belt rocks were deposited in a structural trough some 1.4 to 0.8 billion years ago. These are some of the older rocks—some more than 1.2 billion years old. Although we are traversing slightly younger rocks, all of these rocks are at least a billion years old.

Above us, Middle Proterozoic Appekunny Formation siltstones and silty sandstones comprise the oldest bedrock along this route. In lower areas, the Appekunny is covered by glacial till and landslide debris, so we do not see it in place until we climb high above Cerulean Lake.

The bright green to olive siltstones are easily eroded, and this formation is often located covered in the U-shaped valley floor. The Appekunny Formation reaches a maximum thickness of about 600 meters throughout Glacier National Park. It is interbedded with the overlying Grinnell Formation and the contact is defined by subtle changes in color and lithology.
Stop 8—An Arête, Grinnell Formation (elevation 1,912 meters)
We are now on an arête, a steep-sided, sharp-edged bedrock ridge formed by two glaciers eroding away on opposite sides. Many glacial geomorphology terms, including arête, come directly from other languages—French, German, and Scandinavian. Arête is a French word that means “ridge” or the “bridge of one’s nose.”

The Grinnell Formation ranges in thickness from about 500 to 800 meters and has white, rounded, cross-bedded quartzarenite containing red argillite chips and pellets. Red to purple laminated siltstone and argillite are interbedded within the unit.

Stop 9—Rainbow Glacier, Empire Formation (elevation 2,376 meters)
Continue ascending the Rainbow arête and watch to the north for the first view of glacial ice. Rainbow Glacier, one of the largest in the park, sits high above the headwall of the Cerulean Lake cirque. Its location and form on the steep slope above the cirque could lead to its classification as a hanging glacier. Can you imagine the glacial ice slowly moving down this steep slope? Most glaciers and ice fields in the park are melting, or retreating, at measurable rates.

The Empire Formation is a thinly laminated, dark-green and light-green dolomitic argillite and silty argillite. Ripple marks, desiccation cracks, and mud chips can be seen in many places. Watch for pyrite cubes in carbonaterich strata and, possibly, copper minerals. The Empire Formation is about 150 meters thick.

Stop 10—Summit Ridge, Helena Formation (elevation 2,628 meters)
This ridge is quite high and steep but fortunately this is a virtual climb, so we can cover some very rough country quickly. At the base of the summit ridge of Rainbow Peak, the terrain is noticeably steeper. The bedrock above us appears hard and very resistant to erosion.

The Helena Formation is the most carbonate-rich unit in the Belt Supergroup. The dominant hard dolomite and limestone create an erosion-resistant unit that forms spectacular arêtes and horns. The Helena Formation changes thickness rapidly across Glacier National Park, increasing from about 400 meters to about 2,100 meters in the Swan Range to the southeast. In the Quartz Lake area, where the upper part of the unit is eroded, the formation is 500 meters thick.

Stop 11—The Summit of Rainbow Peak (elevation 3,014 meters)
We are standing on top of Rainbow Peak, the highest point for miles—what a view! Rainbow Peak is a classic horn. Its pyramid shape was created by several glaciers that eroded away different sides of the same mountain. The active Rainbow Glacier continues to erode the east face of Rainbow Peak and earlier formed two smaller cirques on the south and northwest sides. Erosion-resistant Helena Formation limestone and dolomite create a striking terrain.

If you have additional time, follow the arête leading east from Rainbow Peak to Carter Peak at an elevation of 3,000 meters before starting back to Quartz Lake along our original route.

An accompanying, “Modeling Data from the USGS Seamless Site,” describes how to build the model used for this virtual hike in ArcMap using data from the Seamless Data Distribution System.

Glossary of Glacial Geomorphology

Adapted from a Web site (www.uwsp.edu/geo/faculty/lemke/alpine_glacial_glossary/glossary.html) created by Karen A. Lemke, a professor in the Geography/Geology Department at the University of Wisconsin, Stevens Point.

**Arête**—A steep-sided, sharp-edged bedrock ridge formed by two glaciers eroding away on opposite sides of the ridge.

**Cirque**—A semicircular or amphitheater-shaped bedrock feature. It is created as glaciers scour back into the mountain and is where the snow and ice forming the glacier first accumulate; it is the “headwaters” of a glacier.

**Cirque glacier**—A small glacier that occupies a cirque but does not extend down valley from the cirque.

**Col**—A low spot or pass along a cirque or an arête.

**Hanging valley**—A valley eroded by a small tributary glacier such that the elevation of the valley floor is higher than the elevation of the valley floor that the hanging valley joins. The erosive power of glaciers is dictated by their size. The larger a glacier is, the farther down into the landscape it can erode. Consequently, the valley floor of a small tributary glacier will be higher in elevation than the valley floor of the larger glacier that the small tributary glacier joins.

**Headwall**—The steep back wall of a cirque.

**Horn**—A pyramid-shaped mountain peak created by several glaciers that have eroded away different sides of the same mountain.

**Ice fall**—The ice equivalent of a waterfall. As ice flows over a drop-off, it may break apart and then reform at the base of the drop-off.

**Moraine**—An accumulation of unconsolidated material deposited by glaciers. These accumulations tend to be unsorted—many different sized particles are deposited in moraines, ranging from fine silt to large boulders. The sediment and rock material in moraines also tend to have angular edges. There are many different types of moraines, and the appearance of moraines can vary.

**End or terminal moraine**—An accumulation of unconsolidated material deposited at the snout end of a glacier. In alpine areas, moraines tend to form as ridges, but the actual size of the ridges may vary considerably. The ridges extend across the valley that the glacier filled and may be curved slightly down valley. There are two types of end moraines: terminal and recessional. Terminal moraines mark the farthest extent of glacial advance and thus are the end moraines located at the lowest elevation. Recessional moraines form as glaciers pause during periods of retreat and thus are located at higher elevations than terminal moraines. After glaciers retreat, these end moraines may be altered or destroyed by subsequent fluvial erosion.

**Ground moraine**—Unconsolidated material deposited directly beneath the base of a glacier.

**Lateral moraine**—Unconsolidated material deposited along the sides of an alpine glacier. Lateral moraines may form on top of existing alpine glaciers along the sides of the valley walls. Weathering resulting from freezing and thawing causes debris to fall on top of the glacial ice and form a ridge. As glaciers melt, this material may be deposited on the landscape as a ridge.

**Medial moraine**—A moraine formed on top and in the middle of an existing glacier. When two alpine glaciers flow together, their lateral moraines join and form a medial moraine. As glaciers melt, this material is deposited on the landscape but will most likely not be recognizable as material formerly part of a medial moraine.

**Paternoster lakes**—A chain of lakes in a glacial valley.

**Tarn**—A glacial lake produced by scouring that is often found in a cirque.

**Truncated spur**—A drainage divide that has been cut off as glaciers straighten the valleys they erode.

**U-shaped valley**—A glacially eroded valley; also called a glacial trough.

**Valley glacier**—An alpine glacier flowing in a valley. In mountainous regions, glacial flow is restricted by the valley walls. These glaciers start in cirques and extend down valley from the cirque.