# Surficial Geology of Glacier Bay National Park and Preserve

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## Abstract

This 1:100,000-scale surficial geology map of Glacier Bay National Park and Preserve was produced by digitizing published maps, interpreting aerial photography, and systematizing personal observations. The map area also includes the Icy Strait islands, Gustavus, and the Canadian portion of the bay's watershed. Mapping efforts were concentrated on the lowlands, as these deposits are most abundant, complex, and relevant to visitors and management. The 1948 set of aerial photographs was primarily used in mapping, as that set provides the most complete coverage of the map area with the least amount of vegetation, but older and younger photos were also consulted. Sediments were classified in terms of age (Pleistocene, Holocene, or currently active) and how they were deposited (*i.e.*, by streams, glaciers, wind, etc.). In places where there was some knowledge of underlying sediments, this information was captured as well. The result is a map that covers 2,475 km² (exclusive of water, ice, and areas without mappable sediments) and has 1,364 "polygons" belonging to 17 different sediment types.

## Acknowledgements

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## Introduction

The geologic story of the park consists of two distinct chapters: one recorded in the bedrock, which ranges from 400 to 7 million years in age, and a second much younger story written in the surficial sediments whose ages with few exceptions range from ca. 20,000 years ago to the present. Much attention has been devoted to both of these topics, but published maps are almost entirely restricted to the bedrock geology (*e.g.*, Rossman, 1958; MacKevett *et al.*, 1971; Gehrels and Berg, 1992; Brew and Plafker, in preparation). None of the surficial sediment maps are park-wide, being limited to only a few areas instead (*e.g.*, McKenzie, 1970; Mickelson, 1971). Until now there has been no consolidated source of information on the surficial deposits, despite their great importance as a repository of landscape history in a park renowned for its dynamism (*e.g.*, Cooper, 1937). Furthermore, the surficial deposits host most of the lowland plant communities and are an important influence on them, a topic of special interest in Glacier Bay. Lastly, the surficial deposits serve as the sole aquifer for Gustavus, the park's gateway community.

The purpose of this project is to compile a 1:100,000-scale surficial geology map of Glacier Bay National Park and Preserve. At the Park Service's request, we have supplemented the published literature with our own observations, gained formally and informally over the years, and made reasonable suppositions based on both sources of knowledge. This summary represents what is known, or is likely to be true, about the map area's surficial units. The uncertainty level varies from Muir Inlet's relatively well-studied deposits, through the moderately well-known and accessible deposits within the park's Neoglacial ice limits, to the more conjectural map units in the largely unstudied and thickly vegetated areas outside those limits. The intended audience includes park managers, other researchers from an array of scientific disciplines, park interpretive and educational staff, and members of the general public that are particularly interested in the origins of landscapes. As a result, this map attempts to use a language that is accessible to non-geologists while preserving the technical information desired by specialists.

## Study Area

Glacier Bay National Park and Preserve, and some adjacent areas (the Icy Strait / Cross Sound islands, Gustavus, and the Canadian portion of the Bay's watershed), were mapped. Emphasis was placed on the deposits of the "lowlands;" less attention was given to high-altitude areas as deposits there are generally thin or absent. No attempt was made to map deposits below mean high tide, although there is a growing body of literature on the area's submarine geology (*e.g.*, Cowan *et al.*, 1988; Seramur *et al.*, 1997; Cowan *et al.*, 2010; Trusel *et al.*, 2010). We use the term "lowlands" to refer to areas with gentle to moderate slopes. These areas are generally within a few hundred meters of sea level, but in places where moderate slopes are fairly continuous, such as around Hugh Miller Inlet and Scidmore Bay, the actual elevations may climb higher than 600 m and include rounded ridge tops. In other locations, such as along Rendu Inlet, which is steep-sided, the lowlands are limited to elevations of less than 30 m by our definition. Our procedure was to start mapping at sea level and work up slope until mappable deposits became discontinuous; as indicated above, that elevation was quite variable.




## Methods

### Map Unit Minimum Requirements

A sedimentary unit was considered mappable if:
1) Sediments were estimated to be generally greater than 2 m thick, and
2) They comprise a more or less contiguous unit larger than 30,000 m² (which is ~ 5½ US football fields, including the end zones).

In almost every case we could only estimate sediment thicknesses based on aerial photography and our experiences in this landscape.

### Sediment Bodies

The sedimentary units defined in the legend are, in general, classified both in terms of their age and sediment type. The age classification is as follows:

1) Modern - deposits less than about 100 calendar years old
2) Holocene - deposits between about 100 calendar years old and 10,000 ¹⁴C years old
3) Pleistocene - deposits greater than about 10,000 ¹⁴C years old

The one exception to this classification scheme is colluvium, which was not separated into distinct age categories because of the great difficulty in determining the ages of these deposits. The distinction between Modern and Holocene was often difficult to make because of the rapid changes in vegetation that take place on recently stabilized surfaces.

The sediment classification is follows:

| | |
|---|---|
| Stream Sediment (S) | Ice-Contact Sediment (I) |
| Till (T) | Till Over Layered Sediment (T/S) |
| Lake Sediment (L) | Marine Sediment (M) |
| Colluvium (C) | Wind-Blown Sediment (W) |

Combining these two classification schemes results in the units described in the Legend.

## Legend

- **Streams.** Rivers are marked on the map by blue lines. The **gray background** is shaded to represent the topography. The landscape is illuminated as if the sun was in the northwest and 45° above the horizon.
- **Snow / Ice.** Areas of glaciers or permanent snow cover as of ca. 2000.
- **Completely Unmapped.** Only applied to Chichagof Island and nearby islets in Cross Sound / Icy Strait.
- **No Mappable Sediments.** Areas where sediments, if present at all, are less than 2 m thick and/or are in discontinuous bodies of less than 30,000 m². See Figures 3, 23, and 24.
- **Water.** This unit includes all water bodies of more than 30,000 m², regardless of their salinity.
- **S1** **Modern Stream Sediment.** This unit is generally comprised of sand and/or gravel layers. Boulders are possible near former ice margins. The individual stones are often rounded due to tumbling in turbulent streams. See Figures 1, 2, 3, 10, and 12.
- **S2** **Holocene Stream Sediment.** Similar to Modern Stream Sediment, but deposited between about 100 calendar years ago and 10,000 ¹⁴C years BP. See Figure 17.
- **S3** **Pleistocene Stream Sediment.** Similar to Modern and Holocene Stream Sediment, but deposited more than 10,000 ¹⁴C years BP.
- **I1** **Modern Ice-Contact Sediments.** A mixture of rounded-to-angular rock fragments of all sizes with varying degrees of layering that were deposited on, adjacent to, or under glacial ice in the past 100 calendar years. This category includes eskers, kames, and hummocks. See Figures 7 through 13.
- **I2** **Holocene Ice-Contact Sediment.** Similar to Modern Ice-Contact Sediments, except deposited between about 100 calendar years ago and 10,000 ¹⁴C years BP.
- **I3** **Pleistocene Ice-Contact Sediment.** Similar to Modern and Holocene Ice-Contact Sediments, but deposited more than 10,000 ¹⁴C years BP.
- **M1** **Modern Marine Sediment.** The portions of modern beaches that are located above mean high tide, which was the lower elevation limit of our mapping. See Figure 21.
- **M2** **Holocene Marine Sediment Complex.** Sediments deposited in a saltwater environment between about 100 calendar years ago and 10,000 ¹⁴C years BP that have since been isostatically rebounded above the modern mean high tide line. Unlike the Modern Marine Sediment Complex, this unit can include the fine-grained sediments deposited in deep water. See Figure 21.
- **M3** **Pleistocene Marine Sediment Complex.** Similar to Holocene Marine Sediment Complex except deposited more than 10,000 ¹⁴C years BP. The term "Complex" is attached to these map units to emphasize the wide range of sediments that can be found within them. This unit incorporate sediment sizes ranging from silt and clay to boulders, depending on the energy of the depositional environment. See Figure 26.
- **L1** **Modern Lake Sediment Complex.** Sediment, generally ranging in size from sand to clay, that was deposited below the surface of a lake. This category includes the fine-grained sediments of lake floors as well as the coarser-grained sediments of deltas and beaches. See Figures 14 through 16.
- **L2** **Holocene Lake Sediment Complex.** The same as the Modern Lake Sediment Complex, but deposited between about 100 calendar and 10,000 ¹⁴C years BP. See Figure 16.
- **T1** **Modern Till.** Rounded-to-angular sediments of any size directly deposited by a glacier, not inferred to overlie thick layered deposits and deposited within the last 100 calendar years or so. See Figures 5, 6, and 12 through 15.
- **T2** **Holocene Till.** Identical to Modern Till in characteristics but deposited between about 100 calendar and 10,000 ¹⁴C years BP. See Figures 17 and 18.
- **T/S2** **Holocene Till over Layered Sediment.** Identical to Holocene Till (T2), except that these till units overlie thick deposits of layered sediments. The layered sediments are generally of a stream, lake, and/or marine origin. See Figures 4, 19, and 20, as well as the photos of till and layered sediments individually.
- **T3** **Pleistocene Till.** Identical to Modern and Holocene Till in many ways, although more weathered by the passage of time, Pleistocene Till was deposited by glaciers prior to 10,000 ¹⁴C years BP. See Figure 26.
- **C** **Colluvium.** Loose, unsorted deposits at the foot of a slope or cliff, brought there by gravity. We did not separate it into age categories because dating these deposits is particularly challenging. See Figures 1, 3, and 22.
- **W1** **Modern Wind-Blown Sediments.** Sand that has been moved and deposited by the wind within the last 100 calendar years.
- **End Moraines.** Ridges of till and other glacially-transported debris that form along the margins of glaciers when they stabilize in one position or advance forward.
- **Glacier Bay National Park and Preserve Boundary.**

## Field Examples of the Map Units

In order to aid novice geomorphologists in gaining a practical sense of what the map units look like on the ground, we have selected a few photographs to illustrate Glacier Bay's landforms and sediments. Modern examples are shown more frequently than Holocene and Pleistocene ones because the older features are generally too vegetated for easy viewing. The photographs are all either oblique views from low-level flight or the ground and all of them are more detailed than the map. As a result, we have refrained from identifying the photo locations because they generally depict features that are too small to map at a scale of 1:100,000.



**Figure 1:** Low-level oblique aerial photograph of an alluvial fan mapped as modern stream sediment (S1). Colluvium (abbreviated as "C" on the map) surrounds the fan on two sides and water is on the third side. The letter "N" indicates deposits not thick enough to map.

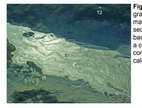


**Figure 2:** Oblique aerial photograph of braided stream surface mapped as S1 (modern stream sediment). The surface in the background is older till (T2). I1 is a collapsing ice-contact sediment complex that is less than 100 calendar years old.



**Figure 3:** Aerial photograph of braided stream surface mapped as S1 (modern stream sediment) and colluvium (C) as indicated. Higher areas have sediment too thin to map (N).




**Figure 4:** Vertical face showing thin till over Holocene sand and gravel (T/S2) near Wachusett Inlet.



**Figure 5:** Freshly exposed till surface (T1) near the Burroughs Glacier.



**Figure 6:** Recently deposited till (T1) being exposed by a retreating glacier edge (upper left). The shovel handle is about 20 inches long.



**Figure 7:** Ground-based photo of debris-covered ice (I1– ice contact sediment complex). Note the circled people for scale.

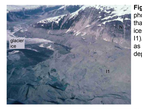


**Figure 8:** Low-level oblique aerial photograph of debris-covered ice that is actively melting (modern ice-contact sediment complex–I1). Clean glacier ice was mapped as "snow / ice". Upland has deposits too thin to map (N).

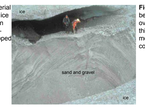



**Figure 9:** Close-up of esker being exposed by the melting of overlying ice. Without ice cover this would be mapped as a modern ice-contact sediment complex (I1).

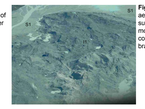


**Figure 10:** Low-level oblique aerial photograph of hummocky supraglacial debris mapped as a modern ice-contact sediment complex (I1) and as a modern braided stream surface (S1).

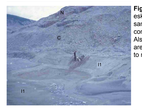


**Figure 11:** Close-up of a small esker and surrounding collapsing sand and gravel (modern ice-contact sediment complex – I1). Also shown is colluvium (C) and areas were deposits are too thin to map (N).

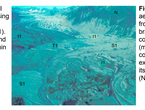


**Figure 12:** Low-level oblique aerial photograph of an area in front of a glacier showing modern braided stream surface (S1), collapsing sand and gravel (modern ice-contact sediment complex – I1), and a freshly exposed till surface (T1). Deposits on upland are too thin to map (N).

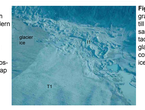


**Figure 13:** Oblique aerial photograph showing recently exposed till surface (T1) and collapsing sand and gravel (modern ice contact sediment complex – I1). The glacier ice has a very thin debris cover and so is mapped as "snow / ice."



**Figure 14:** Ground photo of a modern lake-sediment complex (L1) and recent till (T1). The lake sediment on the far side is deposited upon sand, gravel, and till.



**Figure 15:** Ground photo of a modern lake sediment complex (L1) and recent till (T1). Shovel handle is about 20 inches long. Lake sediment is sand and indicates at least two lake levels.

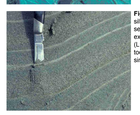


**Figure 16:** Close-up of sand- and silt-sized particles typical of lake sediment complexes. This example is from a modern one (L1) but Holocene (L2) and Pleistocene (L3) examples would be similar.



**Figure 17:** Low-level oblique photo of a fully vegetated outwash plain (S2) and modern braided stream sediment (S1). Uplands are covered with thin till (T2).



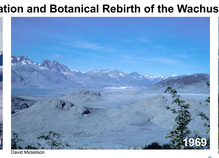
**Figure 18:** Oblique photo of fully vegetated uplands with thin till (T2) and a fully vegetated and stabilized ice-contact sediment complex (I2). A small area of modern stream sediment is also visible (S1).

## The Deglaciation and Botanical Rebirth of the Wachusett Inlet Area
















A 5-photo sequence illustrating 58 years of environmental change in Glacier Bay. The position is William Field's station #7 in the Curtis Hills, north of Wachusett Inlet, and the view is to the west.

## Methods Continued

### Glaciers

Glaciers are mapped as they occurred in ca. 2000. They were derived from SRTM (Shuttle Radar Topography Mission) elevation data and a mosaic of high-quality LandSat images, which were acquired between August 1, 1999 and September 3, 2002. The SRTM data were acquired by the *Space Shuttle Endeavour* in February 2000. Because of the great difficulty in distinguishing areas of permanent snow from glaciers, this unit is called "snow / ice" on the map. Readers interested in documenting changes in glacier extents are encouraged to consult primary sources such as photographs and satellite imagery.

### Water Bodies

Lakes and ponds larger than 30,000 m² are shown on the map; smaller water bodies are generally not. These features were mapped from aerial photography, satellite images, and the SRTM elevation data. The marine shoreline was mapped from the SRTM data alone.

### Areas of "No Mappable Sediments"

Areas not mapped as water, snow / ice, or some kind of sediment are classified as having "no mappable sediments." This map unit might more simply be called "bedrock," but we prefer the term "no mappable sediments" for it better captures reality. In many localities these are areas of thin, patchy till or colluvium while in others it is in fact bare rock. The phrase "no mappable sediments" best reflects this unit's actual essence. In addition to its gray color, it is identified on the map by the letter "N" in potentially confusing locations. See Figures 1, 3, 8, 11, 12, 23, and 24.

### Additional Information

For additional information on how this map was produced and what the units represent, please see the NPS Technical Series Report that accompanies it: NPS/GLBA/NRTR - 2012/XXX.

## Results

The result of this effort to compile and systematize published and unpublished information on the surficial sediments of Glacier Bay National Park and Preserve, and a few adjacent areas, is a map covering 15,932 km² with 3,624 different "polygons" belonging to 21 map units. Excluding areas of water, snow / ice, and no mappable sediments leaves 2,475 km² (16% of the total map area) that is sediment covered by our definition. The most abundant units are Holocene Till (T2), Holocene Stream Sediment (S2), and Modern Stream Sediment (S1). Collectively, Holocene-aged sediments cover 70% of the map area while Modern and Pleistocene sediments cover 19% and 11%, respectively. Additional details are in Tables 1 and 2.

| Classification | % of Map Area | Area (km²) |
|---|---|---|
| Water | 24 | 3835 |
| Snow / Ice | 31 | 4907 |
| Surficial Sediments | 16 | 2474 |
| No Mappable Sediments | 29 | 4673 |

**Table 1.** The relative frequency of water, snow / ice, and surficial sediments in Glacier Bay.

| | Stream Sediments | Ice-Contact Sediments | Till | Till/Layered Sediments | Lake Sediments | Marine Sediments | Wind-Blown Sediments | Colluvium | Total: |
|---|---|---|---|---|---|---|---|---|---|
| **Modern** | 13% | 2% | 1% | X | ~0% | 3% | ~0% | | 19% |
| **Holocene** | 26% | 6% | 27% | 8% | 1% | 2% | X | | 70% |
| **Pleistocene** | ~0% | ~0% | 5% | X | X | 5% | X | | 11% |
| **Total:** | 39% | 8% | 33% | 8% | 2% | 10% | ~0% | ~0% | 100% |

**Table 2.** The relative frequency of map units as a percentage of the total *sediment-covered* area. The units are defined in the methods section. Categories, such as "Modern Till over Layered Sediments" and "Pleistocene Lake Sediments," which are not present in the map area, are marked with an "X." All three age categories of "Colluvium" are blank because this unit was not subdivided by age. Totals might differ from expected values due to rounding; all values are correct to the nearest integer. A tilde is used to emphasize this for values that were rounded down to zero, unlike the units marked with an "X," there are in fact units of this classification on the map.

## Conclusions

The first ever surficial geology map that covers all of Glacier Bay National Park and Preserve has been compiled from previously published and unpublished information. The map also covers Gustavus, the islands of Cross Sound / Icy Strait, and the Canadian portion of Glacier Bay's watershed. Exclusive of areas of snow / ice, water, and no mappable sediments, which cover 84% of the map area, it covers 2,475 km² with 1,364 polygons belonging to 17 map units. No attempt was made to map deposits below mean high tide, due to difficulty of observation, and likewise little effort was made to map the deposits of the high mountainous terrain with accuracy.

## Glossary

**¹⁴C age** - the length of time since the death of an organism based on the radioactive decay of an isotope of carbon in its body. Due to historical and scientific reasons, radiocarbon years are not quite the equivalent of calendar years, hence we specify in the report whether we are referring to calendar or ¹⁴C years.
**Alluvial Fan** - a fan-shaped deposit in map view, typically composed of sand and gravel, deposited by a stream. See Figures 1 and 3.
**BP** - an abbreviation for "Before Present," which, by convention, is considered to be 1950.
**Collapse Features** - hummocky or uneven surfaces resulting from the melting of ice buried by sediment. See Figures 7, 8, 10, 12, and 13.
**Delta** - the equivalent of an alluvial fan that is built into a water body.
**Deposits** - material that has accumulated by a natural process.
**Esker** - a ridge generally composed of sand and gravel deposited by a stream in a tunnel beneath a glacier. See Figures 9 and 11.
**Geomorphologist** - a scientist of landscapes.
**Glaciolacustrine** - related to the interaction of glacial and lake processes.
**Glaciomarine** - related to the interaction of glacial and marine processes.
**Holocene** - the last 10,000 ¹⁴C years.
**Ice-Contact Sediment** - sediment (sand, gravel, boulders, etc.) that was deposited on, under, or immediately adjacent to a glacier.
**Isostatic Rebound** - the process by which the Earth's surface rises in elevation as a response to the removal of the weight of glacial ice.
**Kame** - ice-contact sediment, generally sand and gravel, deposited in a more or less conical hill.
**Loess** - an accumulation of silt-sized particles that was transported and deposited by the wind.
**Oblique Aerial Photo** - a photograph taken from a plane or helicopter where the camera was pointing at some angle other than directly downward.
**Outwash** - sand, or sand and gravel, deposited by streams flowing away from a glacier.
**Outwash Plain** - a flat area created by the deposition of outwash. See Figures 2 and 3.
**Pleistocene** - the time span that encompasses the most recent major ice ages between about 2.6 million calendar and 10,000 ¹⁴C years ago.
**Radiocarbon age** - see ¹⁴C age.
**Sediment** - clay to boulder-sized grains deposited by water, wind, ice, or gravity.
**Silt** - particles between 0.625 mm and 0.002 mm in diameter (smaller than sand; larger than clay).
**Stratigraphy** - a collection of discrete sedimentary layers, such as those comprising our map units.
**Topset Beds** - the nearly horizontal layers of sediment deposited by streams on top of a growing delta.

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