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Malaspina Glacier Research Holds Clues To Possible Global Change Scenarios

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The Malaspina Glacier is the largest glacier in Wrangell-St. Elias National Park and Preserve (Figure 1). The glacier, with an area of more than 2,650 km², is covered by a complex system of folded moraines, the result of differences in flow rate and volume between the Malaspina's tributaries. In its lower reaches, the glacier forms a broad, bulbous, gently-sloping, piedmont lobe. The lobe, which covers an area of more than 1,500 km² is the site of an ongoing investigation by the U.S. Geological Survey (USGS), combining field observations and measurements with laboratory analysis of digital remotely sensed data.

Although the USGS has actively investigated the Malaspina Glacier and its surrounding area since the time of I.C. Russell in the 1880s, it was the November 1986 acquisition by the USGS of digital side-looking airborne radar (SLAR) data of the Malaspina Glacier (Figure 2) that resulted in the present study. The investigation has two themes: (1) the use of radar remote-sensing to provide information about the characteristics of the bedrock underlying Malaspina Glacier and the relationship of the bedrock to the glacier's surface features, and (2) the use of radar to provide information about the history of the glacier.

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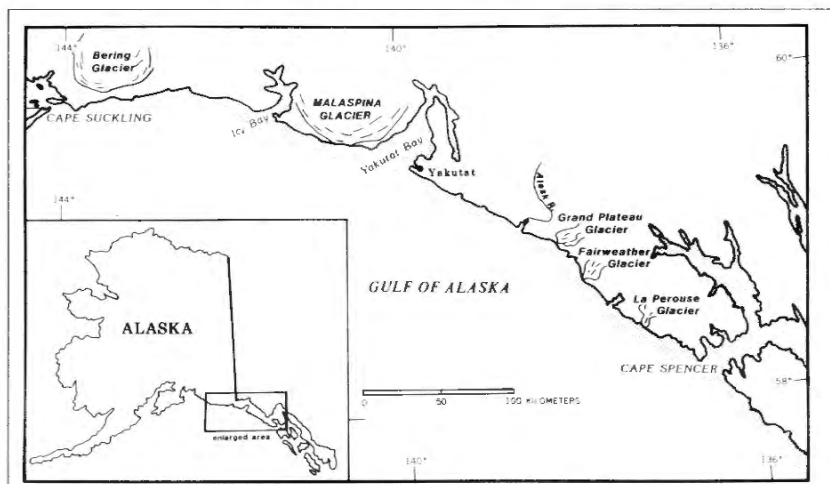


Figure 1. Map showing position of Malaspina Glacier in Wrangell-St. Elias National Park and Preserve.

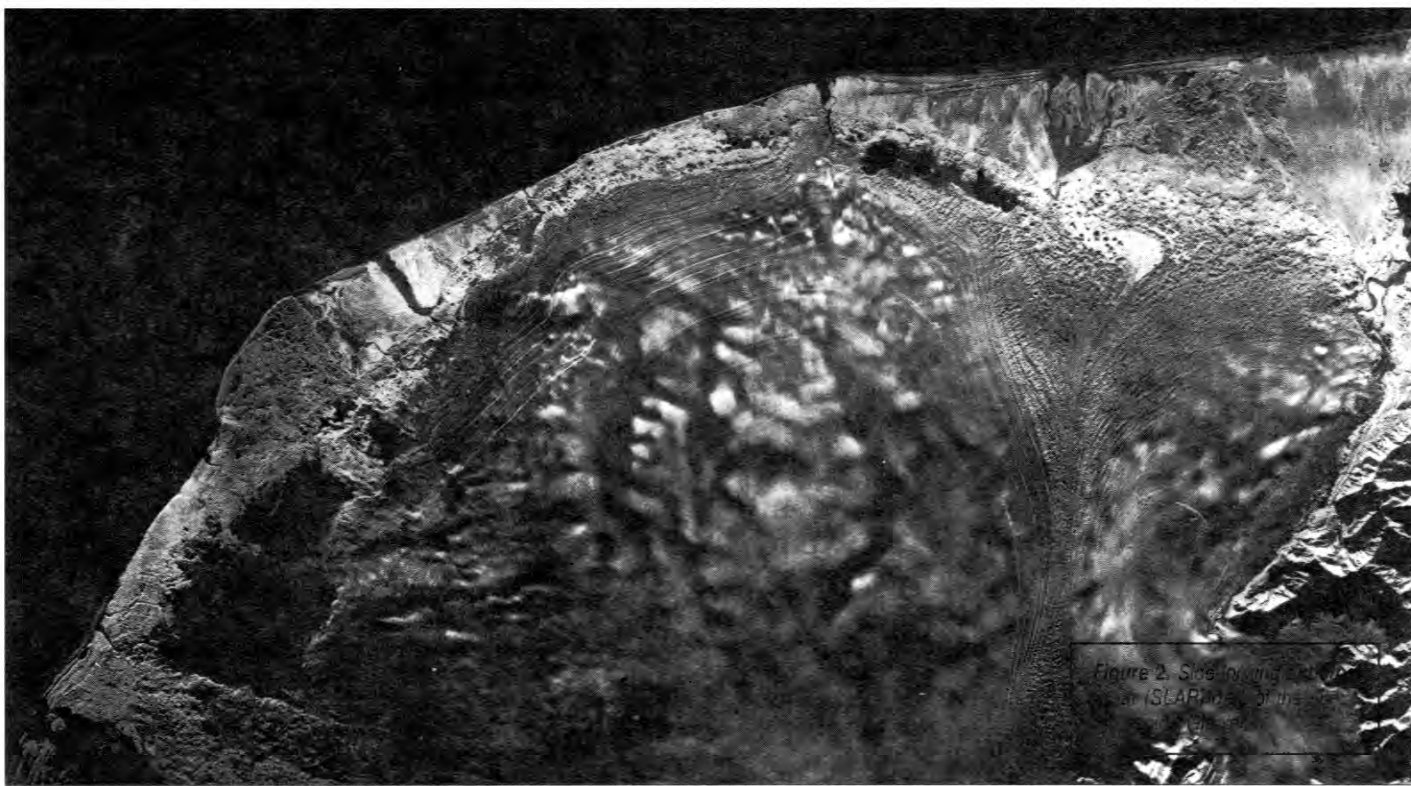


Figure 2. Side-looking airborne radar (SLAR) image of the Malaspina Glacier.

Investigations of the Malaspina Glacier, Wrangell-St. Elias National Park and Preserve

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SLAR is an electronic imaging system that has been used on a worldwide basis by the earth science community, most commonly in petroleum and mineral exploration, sea ice studies, and hydrologic investigations. SLAR data are acquired by an aircraft transmitting a radar beam perpendicular to its flight line. SLAR uses an active sensor, supplying its own source of microwave energy, allowing SLAR data to be acquired either day or night and through most cloud cover. The beam is both reflected and scattered by the ground surface and man-made objects. Energy that is bounced back (backscattered) to the aircraft's receiving antenna is recorded to produce an obliquely illuminated view of the ground, which depicts subtle aspects of surface texture, topography, roughness, slope, and wetness, and the intrinsic electrical properties of materials at or near the surface. SLAR data of the Malaspina Glacier are X-band with a wavelength of about 3.2 cm. The data were collected with a synthetic aperture radar (SAR) system and were polarized to enhance subtle horizontal features such as moraines and crevasse zones. SAR is a radar data storage and processing technology that results in improved resolution.

This study represents one of the first uses of SLAR in investigations of arctic and subarctic glaciers. The 1986 data were the first digitally acquired, airborne radar of coastal, southcentral Alaska and the Malaspina Glacier. The data showed unexpected backscatter responses from the surface of the Malaspina Glacier. Specifically, the radar imagery showed three types of features (glacial-like valleys, dendritic valleys, and an arcuate linear), that were unfamiliar to researchers working with the glacier.

Prior to field investigation of these surface backscatter features, our interpretation was that the features were real, and represented topographic differences on the glacier's surface that mimicked the morphology and relief of the bedrock that underlay Malaspina Glacier. Seismic and gravity investigations, performed in the early 1950s, determined that the ice thickness of the southeastern part of the piedmont lobe was between 500 and 1,000 m and that the bottom of the glacier extended below sea level. However, the details of the morphology of the bedrock basin underlying the glacier were unknown.

Because X-band radar doesn't penetrate more than a few centimeters of snow and ice, we reasoned that the unusual features described here were not the result of the radar "seeing through the ice," rather, they had to be surficial in nature. Consequently, we concluded that in spite of Malaspina Glacier's great ice thickness, there was some direct relationship between ice-surface morphology and underlying bedrock morphology. Understanding this relationship might help in understanding the recent and long-term histories of the Malaspina Glacier and provide insights as to how the glacier might respond to a changing environment.

As observed on X-band SLAR imagery, the three types of features have the following characteristics: GLACIER-LIKE VALLEYS are 10 to 25 km in length and about 1.5 to 2.5 km in width. These valleys are parallel or subparallel to ice flow directions. Cirque-like features, adjacent to some of the glacier-like valleys are less than 1 km across, have abrupt changes in backscatter response across their boundaries, and have rounded amphitheater-like geometries. DENDRI-

TIC VALLEYS are oblique to ice flow directions, are 6 to 12 km in length, and 0.5 to 1.0 km in width. At least 5 distinct east-west trending valleys are present. AN ARCUATE LINEAMENT, a gently curving linear feature that extends in an east-west direction for more than 65 km can be followed from the shoreline of Icy Bay, across outwash sediments and the upperpart of the Malaspina Glacier, to Malaspina Lake. The trace of the lineament may correspond to the trace of the Fairweather Fault or a related boundary fault between the North American and Pacific Plates.

The Malaspina Glacier is the largest glacier in North America and one of the largest outside the icecap regions of the world. The Malaspina Glacier was designated a National Natural Landmark on August 14, 1970. It was determined to be of national significance because of its scientific value.

Field investigations were conducted in 1988 and 1989 to "ground truth" the radar backscatter features. Specifically, investigations were conducted to determine: (1) glacier ice thickness; (2) depth to and configuration of bedrock underlying the glacier; and (3) the relationship of surface backscatter features to surface features and underlying, subglacial-bedrock morphology.

In 1988, field investigations examine the topographic relief, slope characteristics, and other surface conditions of regions of the glacier producing the three types of unusual radar backscatter features. Field work was performed in September to maximize the percent of the glacier's surface that would be snow free. The three features correspond to areas of the surface that are as much as 40 m lower than adjacent areas and are characterized by significantly fewer crevasses, minimal surface relief, a veneer of sediment, and substantially more standing and running water on their surfaces. The lows are generally areas of smooth and featureless ice and appear to be areas of compres-

sional ice flow, while the highs are areas of fractured and broken ice and appear to be areas of extensional ice flow. The ice-surface characteristics in the topographic lows would tend to attenuate or dissipate a radar signal; the result would be a weak backscatter response expressed as a dark feature on radar imagery. The topographically higher ice, adjacent to the lows, with its irregular surface, had numerous "corner reflectors", or surfaces that would provide a strong reflection of the radar signal back to the antenna. Hence, these areas have a strong backscatter and a bright appearance on radar imagery.

Ice-penetrating radar investigations conducted in September 1989 concentrated on determining the thickness of Malaspina Glacier's ice at more than 50 locations. Unlike SLAR, ice-penetrating radar, due to its much longer wavelength (many meters), can measure the depth to bedrock through a kilometer or more of ice. The maximum ice thickness measured at Malaspina Glacier exceeded 850 m, whereas the minimum was only about 150 m. Comparison of ice thickness measurements and ice surface elevations at each site suggests that the Malaspina Glacier occupies a deep basin or series of basins extending well below sea level, and that the southern limit of the glacier coincides with a large moraine complex that occupies part of the basin system. A belt of this moraine is exposed above sea level for more than 10 km at Sitkagi Bluffs and forms the rocky coastal beach that separates the glacier from the Gulf of Alaska. The basin complex underlying the Malaspina Glacier is the product of glacial erosion during a series of advance and retreat cycles extending back into the Pleistocene.

Ice thickness and elevation measurements indicate that at almost every site the base of Malaspina Glacier extends below sea level and that the ice thins significantly in the vicinity of the Sitkagi Bluffs moraine. Northeast of Sitkagi Bluffs, an ice thickness of about 175 m was measured with a basal depth only about 10 m below sea level. By comparison, at Samovar Hills,

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USGS Earth Scientists. Tom Taylor (right), and Bill Schoonmaker, are seen here performing field measurements on Malaspina Glacier.

approximately 50 km north of the southern limit of the Malaspina Glacier, a basin extending more than 250 m below sea level is occupied by about 860 m of ice. The maximum measured depth of the base of the ice below sea level is about 320 m.

Two measurements were made adjacent to Malaspina Lake along the southeast side of the glacier. One detected an ice thickness of about 180 m of ice extending about 75 m below sea level, and the other showed an ice thickness of about 145 m extending about 130 m below sea level.

The measurements at Malaspina Lake and Samovar Hills are very important with respect to the past and future history of the glacier. If, as a result of sea level rise, climatic warming, or coastal erosion, a portion, or all of the terminus of Malaspina Glacier were to be exposed to Gulf of Alaska marine waters, it is possible that the glacier would become an actively calving, rapidly retreating, tidewater glacier. Elsewhere, where rapid tidewater glacier retreat has occurred, such as at the Icy Bay segment of Wrangell-St. Elias National Park, Glacier Bay National Park, and Kenai Fjords National Park, fjords as long as 100 km have been exposed. At the site of the Samovar Hills measurement, even compensating for isostatic rebound, the water depth following glacier retreat would be about 125 m.

A detailed ice-penetrating radar survey with 100-m-spaced soundings was made in the southcentral part of the glacier, an area where radar backscatter features had previously been interpreted to suggest a relationship between ice surface features and underlying bedrock morphology. One transect across a surface low (channel) and its adjacent high found that whereas surface elevations only differed by about 20 m, the thickness of the ice in the area of the high was about 390 m compared to about 590 m in the adjacent low, or 200 m thicker. These data support the described relationship between surface morphology, backscatter features, and bedrock morphology.

Offshore of the Malaspina Glacier, marine seismic data document a series of sediment filled valleys cutting across the continental shelf. When projected under the large terminal moraine, the sea valleys appear to link with the glacier-valley like features seen on the SLAR data.

Several image processing and geographic information systems continue to be used in digital image analysis of the features described here. Additionally, radar data of the Alaskan coastal area from Icy Bay to Grand Plateau Glacier and for much of the southern half of Wrangell-St. Elias NP have been transferred to several CD-ROM disks that also contain public domain image processing software released by USGS and the National Space and Aeronautics Administration.

Field work, including additional ice-penetrating radar studies planned for 1990 through 1993, will continue to carefully measure ice thicknesses and the bedrock morphology underlying Malaspina Glacier and several other glaciers in southern Alaska. With these data in hand, we will have a much more complete understanding of the relationship between ice surface morphology and the topography and morphology of the underlying bedrock. We will also have a much better understanding of the ability of SLAR to provide information about the past and future histories of the Malaspina Glacier system.

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