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# Inventory of the Ahklun Mountain glaciers, southwest Alaska

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Togiak National Wildlife Refuge
Dillingham, Alaska
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Glacier, Ahklun Mountains, inventory.

# Inventory of the Ahklun Mountain glaciers,southwest Alaska

Patrick Walsh, Darrell Kaufman, and Paul Liedberg[1]

## ABSTRACT

The Ahklun Mountains, centered at the northeast quadrant of the Togiak National Wildlife Refuge in southwest Alaska, support the only extant glaciers in western Alaska. These glaciers were originally mapped by the U.S. Geological Survey using photogrammetry methods based on 1972 aerial photos. We digitized their map into a geographic information system, then surveyed for presence or absence of glaciers by fixed-wing aircraft using a GPS-linked computer mapping application that permitted high precision navigation. Of 116 glaciers originally mapped, 109 were surveyed in September 2006. Ninety-seven were verified as extant and 12 (11%) were determined to have disappeared. Of those still extant, many are small fragments of their 1972 extent, suggesting a large decrease in the proportion of land area influenced by glacial ice.

## INTRODUCTION

The global scientific community has long recognized the value of glaciers as indicators of climatic change, and has documented glacial status for over a century (IUGG(CCS) - UNEP - UNESCO 2005.) Glaciers respond sensitively to climate and often provide the most striking and irrefutable evidence of climatic change. Glaciers contract as summer temperature rises or as winter precipitation decreases, or both. Glaciers provide information on climate regimes from both modern-day and prehistoric time perspectives. Glaciers also serve as repositories of fresh water, influencing sea levels globally and contributing to regional hydrologic regimes. It is broadly accepted that water issues will be the most significant natural resource concerns of the 21st century (IAHS - UNESCO 1998). Glaciers strongly impact the discharge of sediment and water downstream, and thereby influence the ecology of riparian and lacustrian habitats within their drainage basins.

Globally, over 67,000 glaciers have been or are currently under study (National Snow and Ice Data Center 2005). However, the Ahklun Mountain glaciers in southwestern Alaska are

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relatively unstudied. Chikuminuk Glacier, the largest Ahklun Mountain glacier, was mapped in 1957 (American Geographical Society 1960), then resurveyed in 1996 by Sapiano et al. (1998), who found that the terminus had retreated at an average rate of ~21 m/yr and that the glacier's area had decreased by ~9% over the 39 year period. Given a difference in methodologies used in the two studies, mass change estimates were uncertain. Manley (1999, see also Molnia 2006) used a GIS approach to calculate 32 physical parameters of the Ahklun Mountain glaciers, including area and elevation. He found a total of 106 glaciers with a median size of 0.26 $km^2$ and a total area of 59.6 $km^2$. He found a range in average elevation from 582 m to 1,176 m with a median elevation of 937 m.

The Ahklun Mountains contain the only glaciers in western Alaska north of the Aleutian Range. These glaciers are relatively small and therefore respond with short lag time compared to larger glacier systems that characterize most of the glacier ice in Alaska. Based on casual observations during the past several years, and comparison with aerial photographs, glaciers in the Ahklun Mountains have lost a significant portion of their mass in the past two decades.

The goals of this project are to inventory and begin monitoring change in the glaciers remaining in the Ahklun Mountains located near the northeastern boundary of Togiak National Wildlife Refuge. This report addresses the first of four objectives:

**Objectives**

1. Inventory the glaciers remaining in the Ahklun Mountains.
2. Document the current areal extent of all known glaciers in the Ahklun Mountains.
3. Document the current extent in three dimensions of a sample of six glaciers in the Ahklun Mountains.
4. Recapitulate all available history of glaciers in the Ahklun Mountains.

## STUDY AREA

During the late Pleistocene Epoch, the Ahklun Mountains supported an extensive ice cap (Manley and Kaufman 2002), covering approximately half of modern day Togiak National Wildlife Refuge (Fig. 1). This area, referred to here as the Ahklun ice cap, was disjunct by >100 km from the Cordilleran Ice Sheet, which covered most of southern Alaska (Kaufman and Manley 2004).

The Ahklun ice cap advanced and retreated during multiple glacial-interglacial cycles of the Pleistocene (Kaufman et al. 2001), sculpting the deeply scoured landscape of the range. During the most recent glacial interval, which culminated about 20,000 years ago, the Ahklun ice cap covered approximately 17,500 $km^2$, and by about 12,000 years ago, it had receded in response to warming climate (Manley et al. 2001). Abundant moraines throughout the Refuge record the fluctuation and stagnation of glacier ice during the transition into the present interglacial interval (Briner et al. 2002). By 9000 years ago glaciers retreated to the highest elevations of the Ahklun Mountains. In the Waskey Lake valley, glaciers are sourced in a granitic pluton, and sediment deposited in Waskey Lake between 9000 and 3000 years ago lacks any indication of granitic rock flour, suggesting that the highest elevations of the Ahklun Mountains were entirely deglaciated during this interval (Levy et al. 2004). Around 3000 years ago, glaciers formed and expanded from the highest elevations, coincident with worldwide cooling of the Neoglaciation. Glaciers in the Ahklun Mountains generally advanced to their most recent maximum extent

during the mid 19th century, late in the Little Ice Age. Glacier termini during the Little Ice Age were generally no more than 1 km beyond their mid 20th century positions.

Currently, the Ahklun Mountains support approximately 100 cirque and small valley glaciers spread throughout an area of approximately 759 $km^2$ (calculated as a minimum convex polygon) located within the highest massifs near the center of the former Ahklun ice cap (Fig. 1). Most glaciers are sourced in north-facing cirques above 1 km elevation that are sheltered by the highest summits. They are concentrated within two massifs, Konarut Mountain in the north, and Mount Waskey in the south.

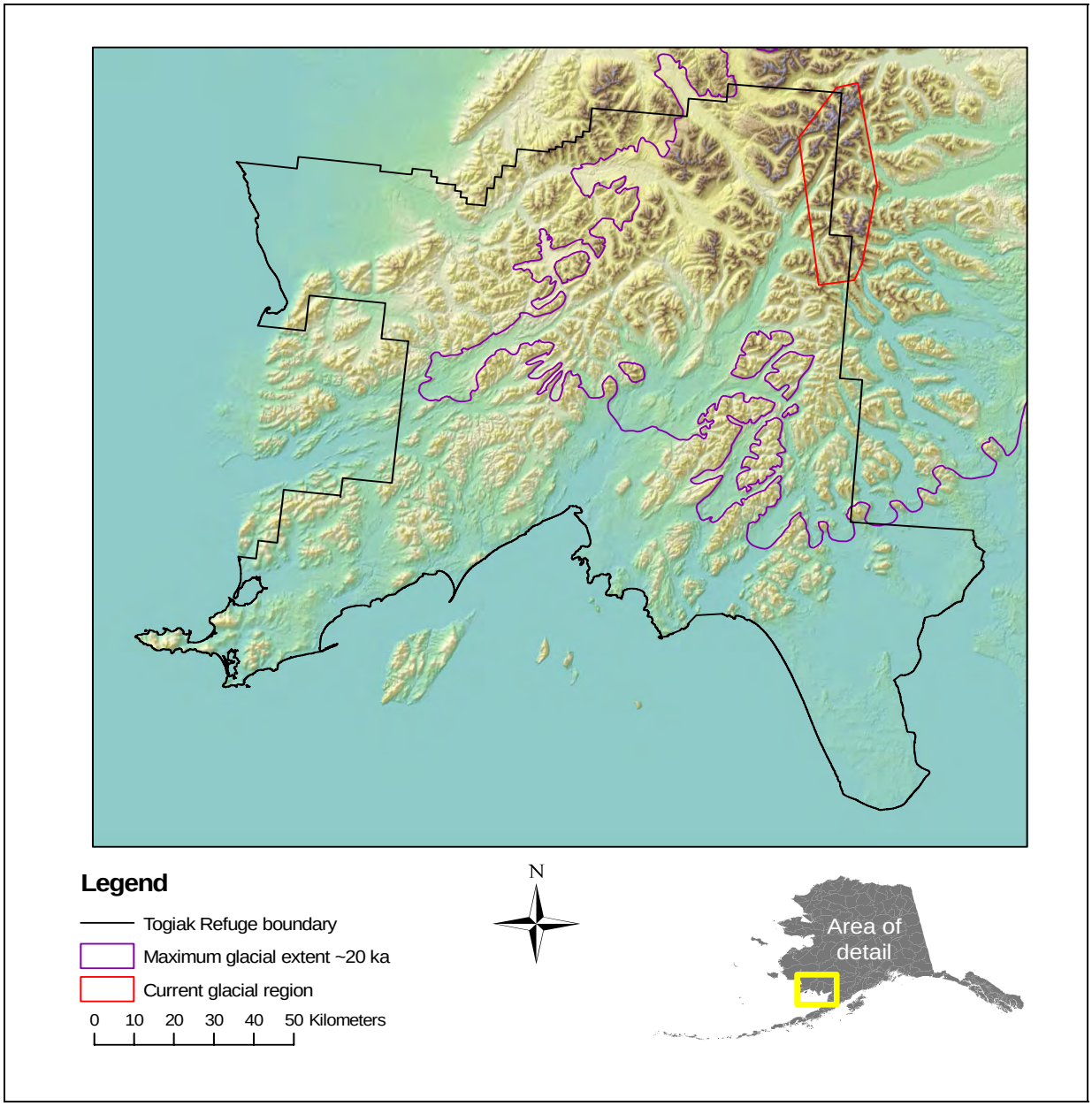


Figure 1. Study area location. Maximum extent of glaciers during late Wisconsonin taken from Manley and Kaufman 2002.

The U.S. Geological Survey (USGS) delineated the extent of Ahklun Mountain glaciers in 1979 onto topographic maps (USGS quadrangles Bethel A-1 and A-2, Goodnews Bay C-1 and D-1). The basis for these maps was aerial photographs taken in the summers of 1972 and 1973. Field checking was not performed.

The climate of the study area currently can be characterized as transitional between subarctic maritime and subarctic continental. The mean monthly maximum and minimum temperature averages -6.3 and -11.3$^{o}$ C in February, the coldest month, and 11.9 and 8.4$^{o}$ C in August, the warmest month (NCDC 1971-2000, Western Regional Climate Center, data for Cape Newenham). Precipitation averages 90.1 cm annually and total snowfall averages 197.8 cm annually.

## METHODS

We performed a GIS inventory of glaciers based on 1:63,360 scale 1979 USGS topographic maps that were scanned into a digital format. We digitized the glaciers into a map using ArcView 3.3 (ESRI 1996). We calculated the area of each mapped glacier using the spatial analysis extension of ArcView 3.3. We determined the elevation of the approximate center point of each glacier using the waypoint tool in TOPO! version 3.4.3 (National Geographic Holding 2003).

Two of us (PW and PL) surveyed each glacier in a tandem two-seater aircraft (Piper Supercub) at an airspeed of approximately 130 km/hr and an approach to within about 400 m above or to the side of each glacier. The glaciers were surveyed during September 2006, at the end of the summer melt season and prior to snowfall. To ensure high precision navigation, location of the aircraft flight path was displayed during flight on a digital map of the glaciers and recorded by a portable computer interfaced with a GPS using ArcPad 6.0 (ESRI 2002). Each glacier was photographed obliquely. Empty cirques that were shown to contain glaciers on USGS maps were also photographed and recorded as absent. Qualitative notes were taken on relative proportions of snow and ice, but no quantitative measures of glacier extent were made. Glaciers within the study area that were incidentally encountered during surveys yet were not previously mapped were recorded and photographed. We did not perform a systematic survey to determine whether other unmapped glaciers were present in the study area.

We categorized the digitized glaciers into two size classes, large (> 0.1 km$^2$) and small (<= 0.1 km$^2$). We tested the hypothesis that over the period 1972 - 2006, small glaciers have a higher likelihood of disappearing than large glaciers using Fisher's exact test for proportions (Hintze 2001) on the numbers of surveyed glaciers we recorded as present or absent.

## RESULTS AND DISCUSSION

Objective 1 was addressed in 2006, and Objectives 2-4 will be addressed in future years. We digitized all 116 glaciers plotted on the 1979 USGS maps (Fig. 2, and see Appendix 2 for expanded view). We found 46.5 km$^2$ of glacier cover. Glaciers averaged 0.40 km$^2$ in area (median size: 0.16 km$^2$, standard error: 0.07 km$^2$, range 0.02 - 6.32 km$^2$). Glacier elevation ranged from 476 - 1295 m (mean: 950.30 m, median: 959.97 m, standard error: 13.35 m) (Appendix 1).

We conducted surveys on 1, 20, 28, and 29 September 2006. One to six photos were taken of each glacier (Fig 3). A light dusting of new snow had fallen by 28 September although glaciers were still distinguishable. Flight speed during surveys averaged 136 kph (range 103-151 kph) and altitude averaged 1,399 m (range 1,140 - 1,566 m).

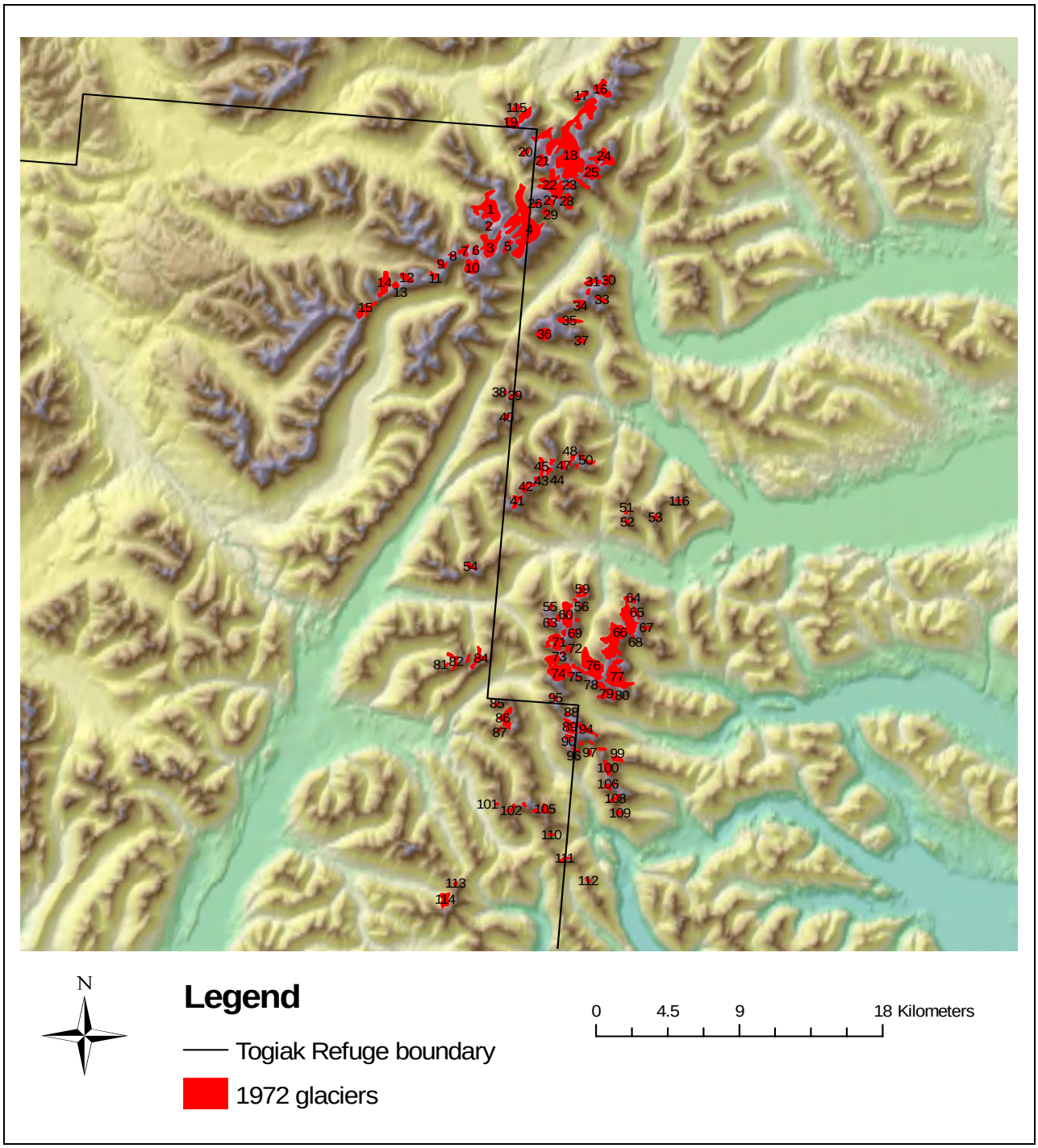


Figure 2. Locations of glaciers mapped by U.S. Geological Survey based on 1972 aerial photography.

We surveyed 109 glaciers and found 97 extant and 12 extinct. Weather prevented access to the remaining seven glaciers. Many of the extant glaciers were small remnants of their 1972 extent. Of the extant glaciers, 27% were categorized as small and 73% as large (Table 1). Of the glaciers that had disappeared, 75% were categorized as small. Significantly more ($P < 0.001$) of the small glaciers disappeared than large.

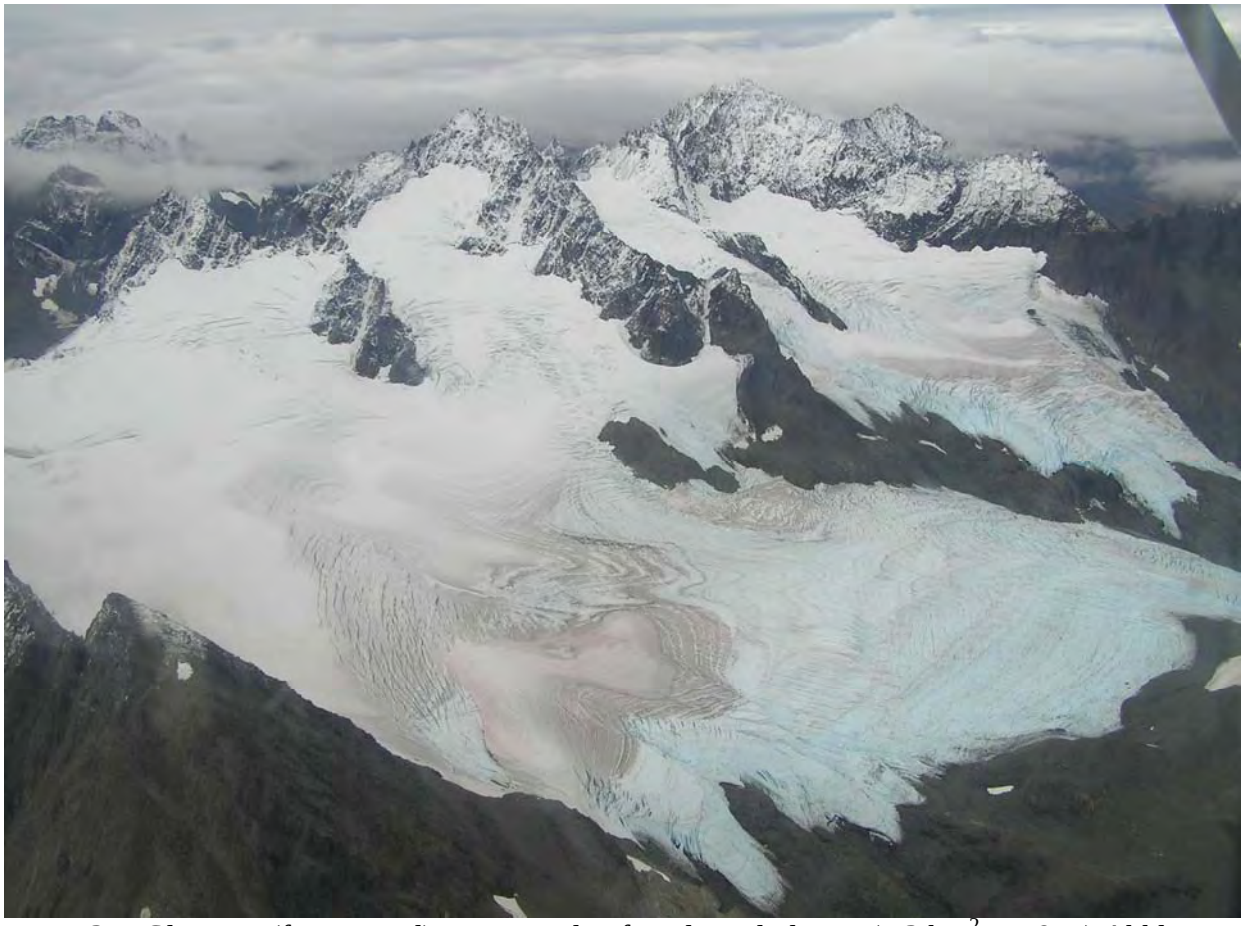

Figure 3a. Glacier 4 (foreground), an example of a relatively large (4.3 $km^2$ in 1972) Ahklun Mountain glacier.

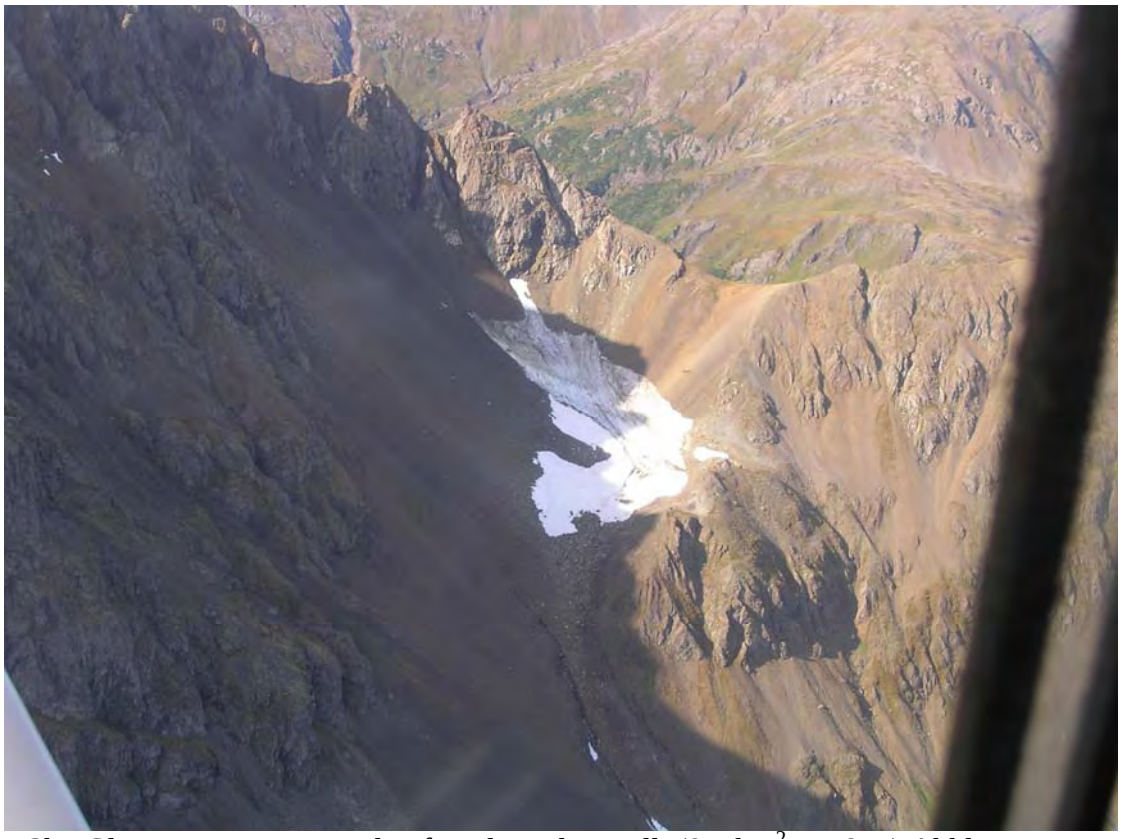

Figure 3b. Glacier 111, an example of a relatively small (0.1 $km^2$ in 1972) Ahklun Mountain glacier.

Figure 3c. Glacier 101, an example of an empty cirque that contained a 0.03 $km^2$ glacier in 1972.

Table 1. Proportion of glaciers that disappeared from time of mapping in 1972 until surveyed in 2006.

| Glacier status | N | Size category N (proportion) | |
|---|---|---|---|
| | | Small | Large |
| Extinct | 12 | 9 (0.75) | 3 (0.25) |
| Extant | 97 | 26 (0.27) | 71 (0.73) |
| Total | 109 | 35 (0.32) | 74 (0.68) |

Incidental to the surveys, we found two substantial glaciers and 17 remnants of what appeared to have been larger glaciers in the recent past (Fig 4) but were not mapped on the original USGS maps. We find it likely that these glaciers were present but not detected during the original mapping.

Figure 4. New Glacier 7, an example of a relatively large glacier not shown during the original mapping.

We conclude that the Ahklun Mountain glaciers are rapidly disappearing since: 1) 11% have ablated completely over a period of 26 years, 2) the smallest glaciers have disappeared at a disproportionately high rate, and 3) many of those remaining appear to be much smaller than in 1972. Assuming that summer temperatures in Alaska continues to increase, we suspect that the rate of glacier extinction in the Ahklun Mountains will increase over the next few decades.

## FUTURE WORK

**Objective 1. Inventory the glaciers remaining in the Ahklun Mountains.**

During the summer of 2007, we will complete this objective by photographing the seven glaciers that were not reached during 2006. We will also seek to understand and rectify if necessary measurement discrepancies between this study and past studies, as our area measurements are different from Manley's (1999).

**Objective 2. Document the current areal extent of all known glaciers in the Ahklun Mountains.**

We will vertically photograph all known glaciers at a scale of approximately 1:5,000 to 1:10,000. Photographs will be geo-referenced and two dimensional areal extent of each glacier will be determined. The new glacier map will be compared with the 1972 USGS maps to determine area changes.

**Objective 3. Document the current extent in three dimensions of a sample of six glaciers in the Ahklun Mountains.**

We will select a subset of approximately six glaciers and accurately document their current extent in three dimensions. Glaciers will be selected as representative of various microclimates and sizes. We will establish an elevational baseline from which future changes can be compared by documenting the change of the glacier surfaces. This will be done by profiling the centerline with high precision location measurements gained through an aircraft-based laser rangefinder combined with GPS. These measurements will be combined with the areal extent gained in Objective 2 to establish the full surface profile.

**Objective 4. Recapitulate all available history of glaciers in the Ahklun Mountains.**

Historical evidence of glacier extents through time will be researched. All available photographs of glaciers will be acquired and the extent of ice at the six study glaciers through time will be quantified.

## ACKNOWLEDGEMENTS

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Appendix 1. Current status of Ahklun Mountain glaciers. Elevation and area were determined from USGS maps based on 1972 aerial photography.

| Glacier | Status | Elevation (m) | Area ($km^2$) | Latitude (degrees) | Longitude (degrees) |
|---|---|---|---|---|---|
| 1 | Present | 1054.61 | 1.70 | 60.0765 | 159.37377 |
| 2 | Present | 1217.68 | 0.12 | 60.06639 | 159.37254 |
| 3 | Present | 1025.96 | 1.15 | 60.05371 | 159.36902 |
| 4 | Present | 1022.60 | 4.34 | 60.06532 | 159.32622 |
| 5 | Present | 1174.39 | 0.20 | 60.05508 | 159.3498 |
| 6 | Unknown | 1065.28 | 0.17 | 60.05042 | 159.38471 |
| 7 | Unknown | 949.45 | 0.29 | 60.04976 | 159.39844 |
| 8 | Unknown | 1071.37 | 0.08 | 60.04671 | 159.40993 |
| 9 | Present | 1034.80 | 0.22 | 60.04043 | 159.42181 |
| 10 | Present | 1119.53 | 0.69 | 60.03981 | 159.38747 |
| 11 | Present | 951.89 | 0.17 | 60.03327 | 159.42905 |
| 12 | Present | 822.35 | 0.30 | 60.03052 | 159.4591 |
| 13 | Present | 1027.79 | 0.13 | 60.02605 | 159.47147 |
| 14 | Absent | 693.72 | 0.77 | 60.02531 | 159.48417 |
| 15 | Absent | 833.02 | 0.53 | 60.01019 | 159.50356 |
| 16 | Present | 876.30 | 0.70 | 60.15403 | 159.25932 |
| 17 | Present | 829.67 | 0.30 | 60.14896 | 159.28203 |
| 18 | Present | 990.90 | 6.32 | 60.11113 | 159.28779 |
| 19 | Present | 853.14 | 0.87 | 60.12965 | 159.3523 |
| 20 | Present | 762.00 | 0.17 | 60.11282 | 159.33898 |
| 21 | Present | 1022.30 | 0.40 | 60.10801 | 159.31893 |
| 22 | Unknown | 911.66 | 1.54 | 60.09257 | 159.30498 |
| 23 | Unknown | 1012.55 | 0.14 | 60.09478 | 159.28577 |
| 24 | Present | 887.27 | 0.91 | 60.11293 | 159.2485 |
| 25 | Present | 1055.22 | 0.77 | 60.10354 | 159.26184 |
| 26 | Unknown | 1108.56 | 0.16 | 60.08151 | 159.32101 |
| 27 | Unknown | 1000.35 | 0.21 | 60.08364 | 159.30566 |
| 28 | Present | 940.61 | 0.37 | 60.08586 | 159.28766 |
| 29 | Present | 831.80 | 0.15 | 60.0774 | 159.30975 |
| 30 | Present | 986.03 | 0.27 | 60.04162 | 159.23339 |
| 31 | Present | 892.15 | 0.30 | 60.03843 | 159.24566 |
| 32 | Present | 1251.81 | 0.08 | 60.03114 | 159.25434 |
| 33 | Present | 860.15 | 0.18 | 60.02694 | 159.23941 |
| 34 | Present | 815.34 | 0.23 | 60.0237 | 159.2599 |
| 35 | Present | 703.78 | 0.35 | 60.01268 | 159.27364 |
| 36 | Present | 1007.97 | 0.56 | 60.00338 | 159.30021 |
| 37 | Present | 791.26 | 0.17 | 60.00092 | 159.25688 |
| 38 | Present | 991.82 | 0.04 | 60.00092 | 159.33758 |
| 39 | Present | 995.17 | 0.17 | 59.96532 | 159.32698 |
| 40 | Present | 934.82 | 0.12 | 59.95161 | 159.33459 |
| 41 | Present | 1066.19 | 0.27 | 59.90233 | 159.31365 |
| 42 | Present | 1086.92 | 0.31 | 59.90942 | 159.30563 |
| 43 | Present | 1048.51 | 0.06 | 59.9154 | 159.29423 |
| 44 | Present | 1099.11 | 0.12 | 59.92114 | 159.28097 |
| 45 | Present | 854.35 | 0.26 | 59.92339 | 159.29009 |
| 46 | Present | 1074.72 | 0.09 | 59.92676 | 159.27871 |
| 47 | Present | 907.39 | 0.14 | 59.92459 | 159.26525 |
| 48 | Present | 949.76 | 0.14 | 59.9286 | 159.25547 |

| | | | | | |
|---|---|---|---|---|---|
| 49 | Absent | 876.30 | 0.04 | 59.92496 | 159.25021 |
| 50 | Absent | 665.68 | 0.18 | 59.92784 | 159.23499 |
| 51 | Absent | 1010.72 | 0.04 | 59.8598 | 159.36024 |
| 52 | Present | 1007.67 | 0.07 | 59.89353 | 159.18832 |
| 53 | Present | 920.50 | 0.07 | 59.89764 | 159.15717 |
| 54 | Present | 996.70 | 0.16 | 59.85967 | 159.35975 |
| 55 | Absent | 958.60 | 0.08 | 59.83861 | 159.26592 |
| 56 | Absent | 890.93 | 0.05 | 59.8401 | 159.23244 |
| 57 | Present | 1039.98 | 0.05 | 59.84378 | 159.23884 |
| 58 | Present | 990.90 | 0.13 | 59.8468 | 159.23292 |
| 59 | Present | 750.72 | 0.16 | 59.8503 | 159.23265 |
| 60 | Present | 1128.67 | 0.83 | 59.83379 | 159.24686 |
| 61 | Present | 830.88 | 0.04 | 59.83178 | 159.23516 |
| 62 | Present | 1148.18 | 0.07 | 59.83184 | 159.25668 |
| 63 | Present | 1146.05 | 0.20 | 59.82872 | 159.2639 |
| 64 | Present | 1064.97 | 0.11 | 59.84625 | 159.17403 |
| 65 | Present | 1080.21 | 0.16 | 59.83898 | 159.16963 |
| 66 | Present | 1039.67 | 3.35 | 59.82663 | 159.18785 |
| 67 | Present | 872.03 | 0.10 | 59.83004 | 159.15796 |
| 68 | Absent | 1083.26 | 0.03 | 59.82403 | 159.17087 |
| 69 | Present | 1005.23 | 0.20 | 59.82387 | 159.23854 |
| 70 | Present | 1226.82 | 0.10 | 59.82342 | 159.24878 |
| 71 | Present | 1086.31 | 0.77 | 59.81852 | 159.25605 |
| 72 | Present | 915.31 | 0.13 | 59.81387 | 159.24145 |
| 73 | Present | 1109.17 | 0.05 | 59.81117 | 159.24772 |
| 74 | Present | 876.60 | 1.77 | 59.80042 | 159.25129 |
| 75 | Present | 1165.86 | 0.04 | 59.79716 | 159.22867 |
| 76 | Present | 837.29 | 1.84 | 59.80316 | 159.21044 |
| 77 | Present | 982.98 | 1.65 | 59.79819 | 159.18579 |
| 78 | Present | 1069.24 | 0.20 | 59.79307 | 159.2024 |
| 79 | Present | 1044.24 | 0.33 | 59.78839 | 159.19632 |
| 80 | Present | 954.33 | 0.19 | 59.78756 | 159.18694 |
| 81 | Present | 958.90 | 0.03 | 59.79872 | 159.37642 |
| 82 | Present | 844.30 | 0.29 | 59.80312 | 159.36664 |
| 83 | Present | 899.77 | 0.06 | 59.80351 | 159.35365 |
| 84 | Present | 719.33 | 0.46 | 59.80425 | 159.34096 |
| 85 | Absent | 982.98 | 0.05 | 59.7772 | 159.31634 |
| 86 | Present | 743.41 | 0.55 | 59.76895 | 159.30748 |
| 87 | Present | 934.21 | 0.05 | 59.76197 | 159.31181 |
| 88 | Present | 979.63 | 0.06 | 59.77441 | 159.23684 |
| 89 | Present | 1175.92 | 0.45 | 59.76687 | 159.23347 |
| 90 | Present | 1153.36 | 0.11 | 59.76084 | 159.23364 |
| 91 | Present | 1295.40 | 0.02 | 59.75867 | 159.2299 |
| 92 | Absent | 841.55 | 0.05 | 59.75735 | 159.21822 |
| 93 | Absent | 896.11 | 0.03 | 59.75836 | 159.20784 |
| 94 | Present | 757.12 | 0.39 | 59.7662 | 159.21665 |
| 95 | Present | 879.35 | 0.11 | 59.78342 | 159.25198 |
| 96 | Present | 998.22 | 0.09 | 59.75284 | 159.22482 |
| 97 | Present | 528.52 | 0.11 | 59.75206 | 159.2085 |
| 98 | Present | 791.57 | 0.09 | 59.75475 | 159.19535 |
| 99 | Present | 740.97 | 0.19 | 59.74964 | 159.17713 |
| 100 | Present | 930.55 | 0.37 | 59.74367 | 159.18684 |
| 101 | Absent | 821.44 | 0.03 | 59.71708 | 159.30656 |

| | | | | | |
|---|---|---|---|---|---|
| 102 | Present | 961.03 | 0.14 | 59.71693 | 159.29249 |
| 103 | Present | 1086.61 | 0.05 | 59.71778 | 159.27632 |
| 104 | Present | 1078.08 | 0.07 | 59.71441 | 159.26352 |
| 105 | Present | 900.68 | 0.23 | 59.71559 | 159.25297 |
| 106 | Present | 972.92 | 0.13 | 59.73221 | 159.18454 |
| 107 | Present | 1025.65 | 0.04 | 59.73373 | 159.17822 |
| 108 | Present | 861.06 | 0.20 | 59.72475 | 159.17718 |
| 109 | Present | 780.90 | 0.10 | 59.71712 | 159.1703 |
| 110 | Present | 819.30 | 0.06 | 59.70081 | 159.24427 |
| 111 | Present | 792.48 | 0.12 | 59.68683 | 159.22604 |
| 112 | Present | 852.53 | 0.05 | 59.67454 | 159.1981 |
| 113 | Present | 778.46 | 0.06 | 59.66679 | 159.34519 |
| 114 | Present | 476.10 | 0.43 | 59.65652 | 159.35563 |
| 115 | Present | 736.40 | 0.19 | 60.1388 | 159.35315 |
| 116 | Present | 999.44 | 0.07 | 59.90844 | 159.13282 |

Appendix 2. Enlarged view of Ahklun Mountain glacier locations based on 1972 aerial photography.

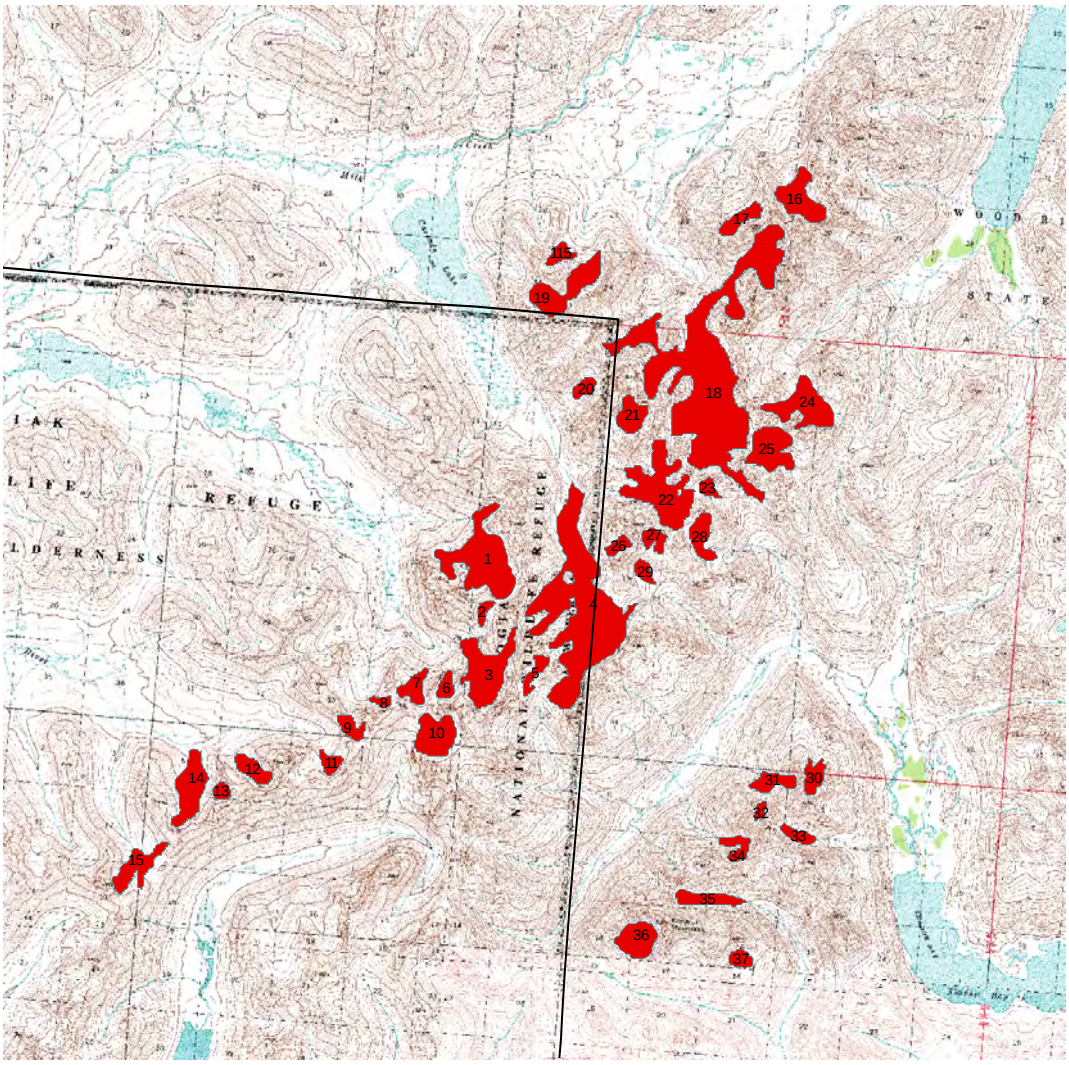


Figure A2-1. Northern glaciers of the Ahklun Mountains.

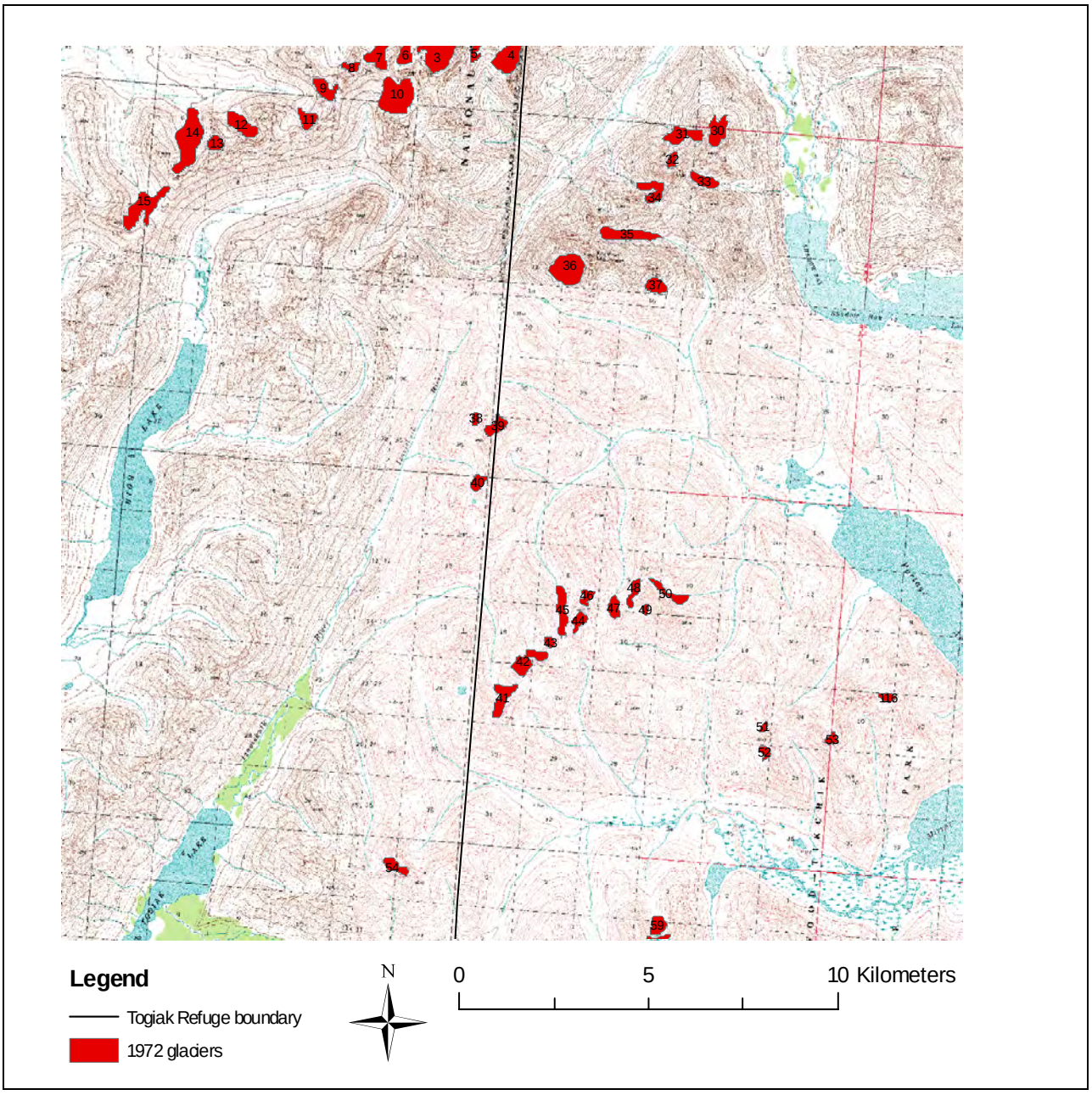


Figure A2-2. Central glaciers of the Ahklun Mountains.

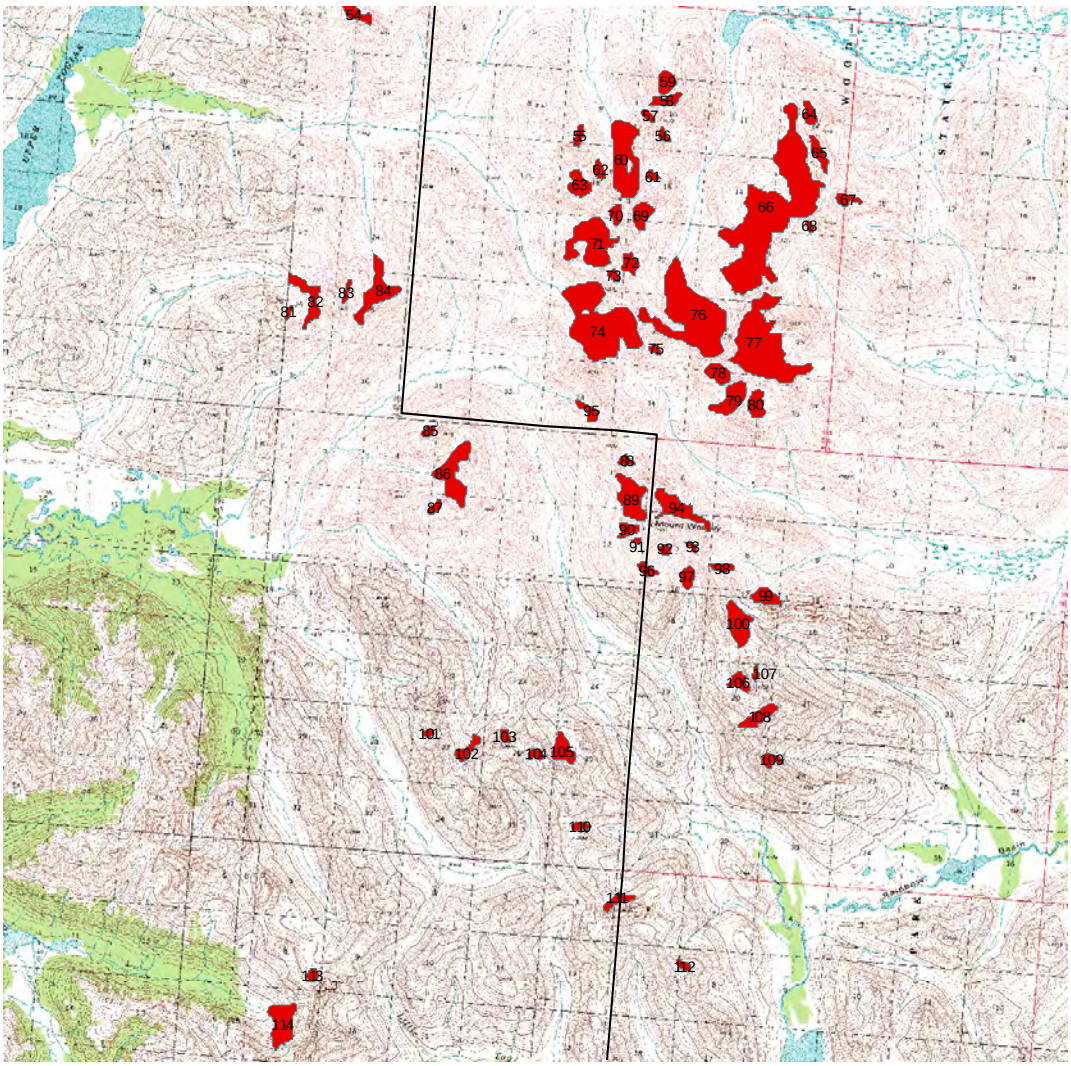


Figure A2-3. Southern glaciers of the Ahklun Mountains.