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National Park Service
U.S. Department of the Interior

Southwest Alaska Network Inventory and
Monitoring Program
240 West 5th Avenue
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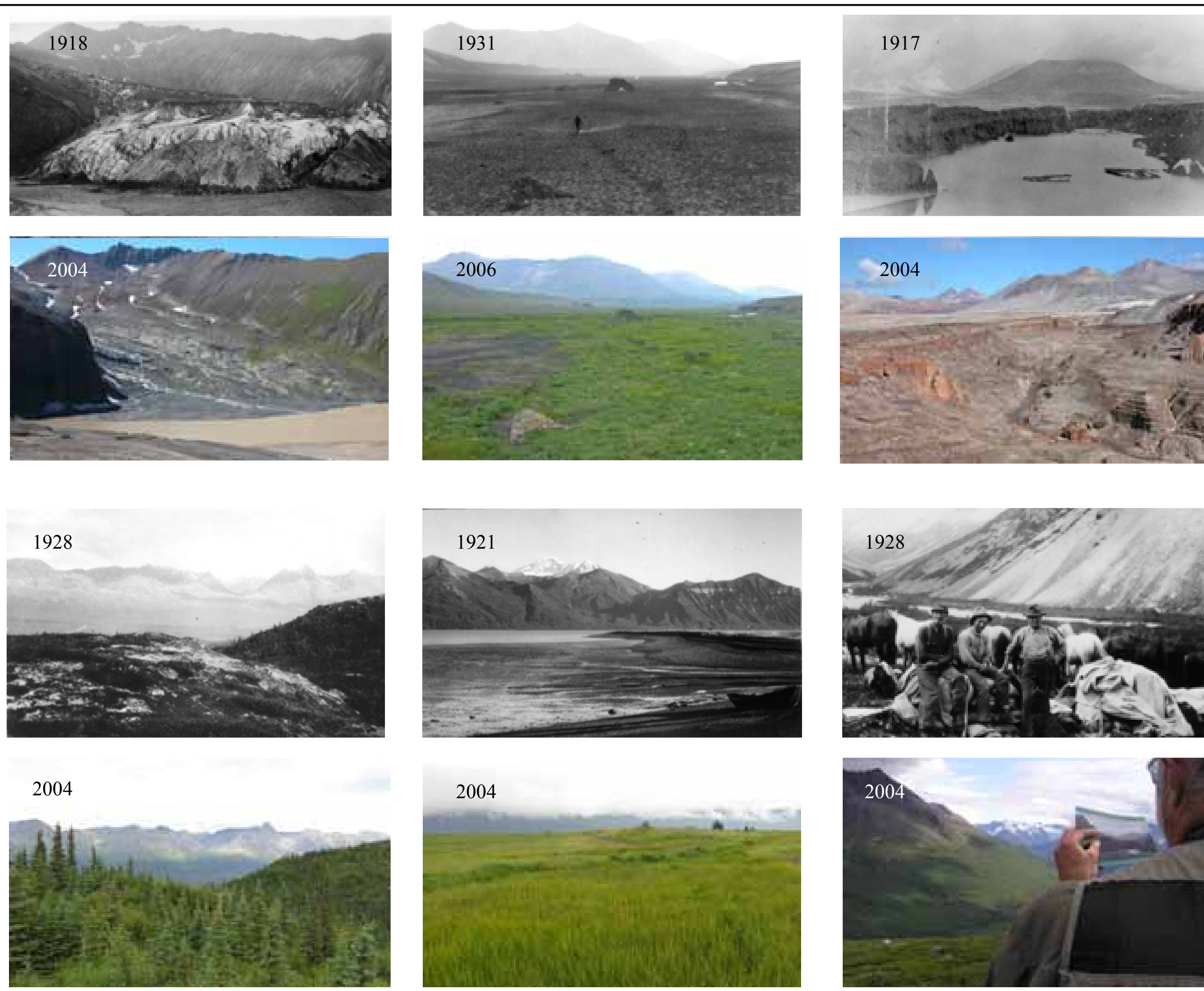
Photographic Monitoring of Landscape Change in the Southwest Alaska Network of National Parklands, 2006

Contract No. D9855033047
Report No. NPS/AKRSWAN/NRTR-2006/03



ON THE COVER

Photo pairs comparing historical and recent photographs of the same locations. Each pair illustrates a variety of dynamic and interacting processes that have occurred over varying timescales.

Top left pair: An unnamed glacial valley in the southwestern corner of The Valley of Ten Thousand Smokes, Katmai National Park & Preserve. The glacier has receded and vegetation has slowly begun to colonize the exposed valley bottom. 1918 photo by J. Sayre, courtesy of National Geographic Society. 2004 photo by G. Frost, ABR, Inc.

Top middle pair: Looking down the Aniakchak River valley ~1 km below Aniakchak Caldera, Aniakchak National Monument & Preserve. Following widespread tephra deposition during the most recent eruption in 1931, a mesic forb meadow with scattered low willows has developed at this site. 1931 photo by B. Hubbard, courtesy of Santa Clara University. 2006 photo by G. Frost, ABR, Inc.

Top right pair: Looking east over a large fissure in the southwestern corner of The Valley of Ten Thousand Smokes. Contraction of 1912 pyroclasts formed several large fissures, including, at this site, the bed of a short-lived lake. 1917 photo by R. Griggs, courtesy of National Geographic Society. 2004 photo by G. Frost, ABR, Inc.

Bottom left pair: Montane slope in the Two Lakes area, Lake Clark National Park & Preserve, at an elevation of 710 m showing recent elevational expansion of white spruce and paper birch trees. 1928 photo by S. Capps, courtesy of U.S. Geological Survey. 2004 photo by M. Jorgenson, ABR, Inc.

Bottom middle pair: Seal Spit in Chinitna Bay near Lake Clark showing the effects of coastal uplift from the 1964 earthquake. 1921 photo by F. Moffit, courtesy of U.S. Geological Survey. 2004 photo by M. Jorgenson, ABR, Inc.

Bottom right pair: Top: Members of a USGS survey party rest from the trail along the Merrill River, 1928. Bottom: Alan Bennett of the National Park Service locates the original vantage point of a 1928 photograph overlooking the Igitna River in Lake Clark National Park & Preserve, 2004. 1928 photo by S. Capps, courtesy of U.S. Geological Survey. 2004 photo by M. Jorgenson, ABR, Inc.

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Abstract

A project was initiated in 2003 to assess landscape changes in the Southwest Alaska Network (SWAN) of National Parks through the use of repeat photography. A total of 1099 historical photographs dating as far back as 1895 have been acquired for Lake Clark (191), Katmai (654), Aniakchak (204), and Kenai Fjords (50). A digital archive structure and *ThumbsPlus*-Access database have been developed to compile information about the photographs and prioritize them for repeat photography. The photographs are stored as high-resolution (~10 Mb tiff) images for archiving and research, and low-resolution (~300 kb jpg) images for rapid review and broader distribution. The primary subjects of the photographs have been categorized as glacier, coastal, floodplain, volcanism, landslide colluvium, avalanche chute, lacustrine, plant succession, shrub expansion, tree expansion, people, and human disturbance. The database allows the user to easily sort and view photographs by the desired data fields. During 2004–2006, a total of 294 photographs were repeated in three SWAN units by ABR and NPS personnel: 59 in Lake Clark; 134 in Katmai, and 101 in Aniakchak. Additionally, 254 photographs were taken of new scenes in Katmai (39) and Aniakchak (215).

Key Words: Lake Clark, Katmai, Aniakchak, Kenai Fjords, Monitoring, Landscape, Change, Photography, National Parks, SWAN, Alaska

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Introduction

Photographic monitoring is an effective method for both qualitatively and quantitatively assessing landscape changes. Repeat photography provides a rapid method for documenting change and can serve as the basis for developing hypotheses for more intensive measurements of change for specific physical or biological components of the landscape. The use of historical photographs can extend the period of monitoring up to a century or more. Historical photographs also stimulate much National Park visitor interest and repeat photography provides an effective way of communicating and demonstrating how natural landscape processes are operating in parklands.

Nationally, repeat photography has been frequently used to document landscape-level and site-level changes (Gruel 1983, Rogers et al. 1984, Humprey 1987, McGinnies et al. 1991, Veblen and Lorenz 1991, Idso 1992, Hart and Laycock 1996, Webb 1996, Skovlin et al. 2000). In Alaska, repeat photography also has been used for a wide range of studies, including glacial dynamics (Hamilton 1965; Field 1983, 1988; Lawrence and Engstrom 1993), thermokarst (Jorgenson et al. 2001, Jorgenson et al. 2006), water-level changes (Hinzman et al. 2005), coastal erosion (Jorgenson et al. 2002, Brown et al. 2003), floodplain dynamics (Jorgenson and Shur 1999), shrub invasion (Sturm et al. 2001, Tape et al. 2006), animal censuses (Burgess et al. 1992, Griffith et al. 2002), plant succession after natural disturbance (Racine et al. 1987, Wang et al. 2004), and human disturbance (McKendrick 1976, Emers and Jorgenson 1997, McKendrick 2000). A comprehensive manual to standardize photo-monitoring methods has been produced by Hall (2002).

This report describes a three-phase effort to develop a photographic monitoring program for the Southwest Alaska Network (SWAN) of the National Park Service (NPS), which includes Alagnak Wild River, Aniakchak National Monument and Preserve, Katmai National Park and Preserve, Kenai Fjords National Park, and Lake Clark National Park and Preserve, in order to provide a historical and future record of landscape processes and biophysical changes that reflect "vital signs" selected for long-term monitoring (Bennett et al. 2006). The effort expanded upon the earlier repeat-photography effort of Wang et al. (2004) to monitor plant succession after volcanism in Aniakchak.

Specific objectives were to:

1) compile historical photographs of landscape features in the SWAN parks and photo management information within a database system;

2) screen historical photographs to identify locations for repeat photography and design a photo-monitoring network; and

3) repeat photographs within the photo-monitoring network and establish photo-monitoring sites at new locations in order to document changes for high-priority landscape features.

Methods and Materials

Work was done in three phases corresponding to the three objectives stated above. Phase 1 consisted of compiling historical photography and creating a photo database. Phase 2 consisted of screening of old photography to determine its usefulness and designing a repeat photography program in order to develop a photo-monitoring network. Phase 3 consisted of acquiring the new photography.

Compilation of Historical Photographs

In 2004, historical photographs were obtained from archives at the U.S. Geological Survey Photographic Library in Denver, CO (265 photographs), the NPS Lake Clark–Katmai Studies Center (170), the University of Alaska Anchorage (63), and the University of Alaska Fairbanks (7). Additionally, 9 photographs were acquired from local park residents in coordination with NPS cultural resource specialists. In March 2005, ~430 photographs for Katmai were reviewed at The Bernard Hubbard Photograph Collection at Santa Clara University, of which 59 were acquired. In addition, 113 of Hubbard's Aniakchak photographs held at Santa Clara and 18 recent NPS photopoint monitoring photographs for Aniakchak were acquired from the NPS field office in King Salmon, AK. In May 2005, ~4800 Robert F. Griggs expedition photographs were reviewed at the National Geographic Society photographic archive in Washington, DC, of which 344 were acquired. In December 2005, 63 photographs were acquired from archives at the National Park Service Regional Office in Anchorage, AK. A further 31 historical photographs have been acquired from miscellaneous sources, including books, magazines, and journal articles. Photographs were scanned from black and white prints (937 photographs), color prints (109), or color slides (18). Additional historical photographs were acquired from online sources at the U.S. Geological Survey (48) and the Alaska Volcano Observatory (8) in digital jpeg (*.jpg) or bitmap (*.bmp) file formats. All photographs acquired from the University of Alaska Anchorage, the University of Alaska Fairbanks, the Santa Clara University, and the National Geographic Society are protected by copyright.

Photograph and slide scanning were conducted using a *Canon* LiDE30 flat-bed scanner at high-resolution (300 dpi for large photos, 600 dpi for small photos) and stored as uncompressed tiff (*.tif) images. Photographs obtained from online sources were downloaded either as digital jpeg or bitmap files at the highest available resolution. Image file names assigned included four components: (1) the park code (e.g., ANIA, KATM, KEFJ, LACL), (2) the 4-digit year of the image, (3) the 3-letter initials of the photographer (first, middle, last), and (4) a photo number with 4 digits derived from the photograph's archival accession number (e.g., ANIA1922wrs0048.tif). Photos were archived at either low-resolution (680 × 480 pixels, ~100–500 kb file size jpegs) for quick retrieval and distribution, or high-resolution (~5−20 Mb tiffs) for detailed analysis or presentation. High-resolution prints (5 × 7 in, 600 dpi) were made of photographs selected for repeat photography and all photographs were archived on CD-ROMs at both resolutions.

Historical aerial photographs were obtained for four locations, Chinitna Bay (1954, 1978), the Kijik River delta (1957, 1978), Lake Clark Pass (1954, 1978), Telaquana Lake (1957, 1978), and the Naknek River mouth (1951, 1973, 1984). Plans to geo-rectifiy these airphotos were suspended pending the receipt of new orthorectified Ikonos imagery by NPS.

An Access-compatible database was created using *ThumbsPlus©* photo-management software to document information on the photograph, including photographer, date of photography, original caption, associated publication (if any), detailed specifications of the photography, the source institution, and subject of the photograph. In addition, estimated geographic locations of vantage points were assigned to historical photographs until precise locations could be determined in the field (during Phase 3). The photo database provides a convenient method for viewing the low-resolution photographs and associated data (Figure 1).

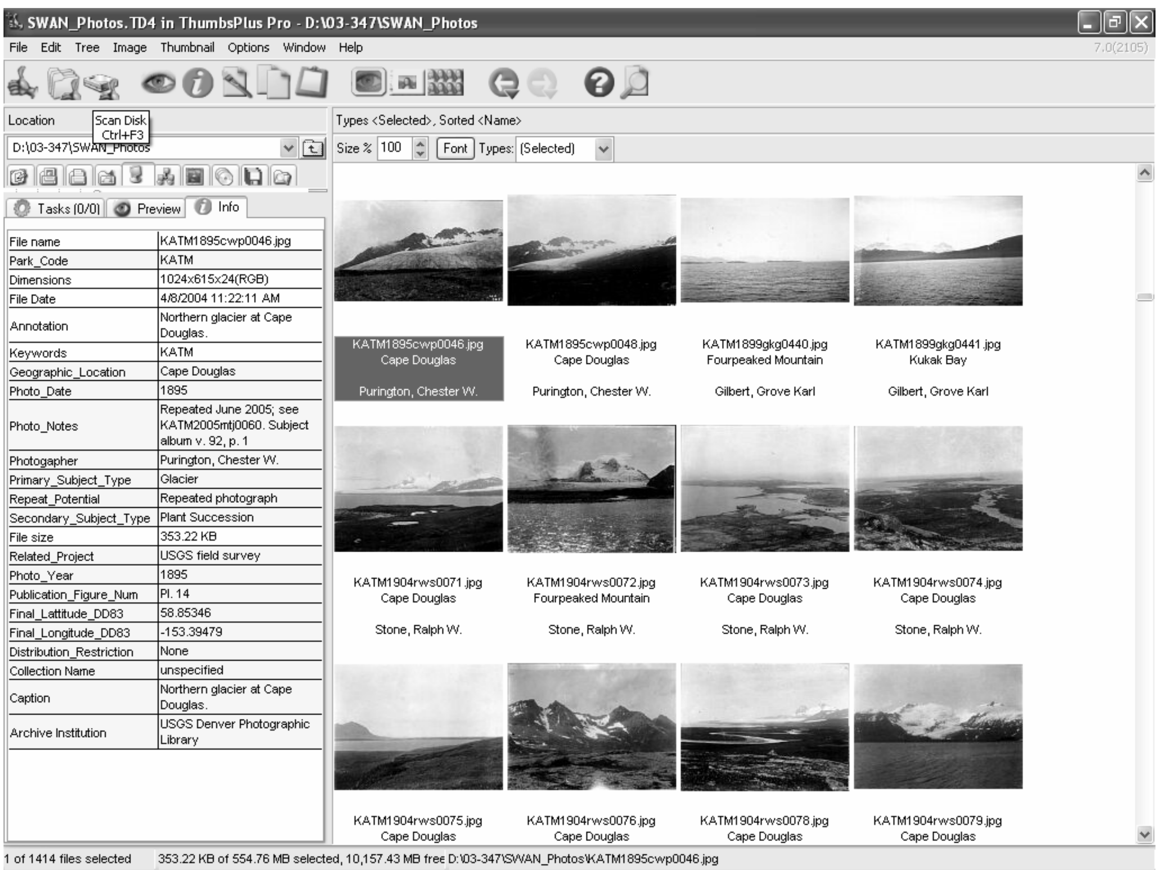

Figure 1. Screen snapshot of *ThumbsPlus©* database created for documentation and management of information associated with each photograph. The program provides photo-management capabilities linked to more comprehensive information residing within an Access© database.

Monitoring Network Development

Photograph management under Phase 2 entailed the evaluation of the usefulness of acquired historical photographs and the design of a comprehensive photo-monitoring network. After review, each historical photograph was assigned a monitoring potential of high, moderate or low. Although by nature a subjective process, the following criteria were used to assess monitoring potential: (1) the presence of photo content sufficient to establish baseline information for one or more biophysical landscape component(s), (2) the presence of landmarks in the photo and/or associated photo caption information permitting the identification of the general photo location, (3) the presence of durable landscape features permitting the triangulation of the precise vantage point in the field, and (4) photo quality sufficient to distinguish the spatial attributes of one or more biophysical landscape component(s). Historical photos that satisfied all four criteria and captured at least one biophysical component thought likely to be subject to biological and/or geomorphic change or disturbance within ~100 years were assigned high potential. Photos that satisfied the first criterion, but that failed to fully meet one of the other three criteria, were assigned moderate potential. Photos that failed to meet two or more criteria were assigned low potential. Photos that met none of the criteria were not incorporated into the historical photo archive. Initial assessments were subject to revision as field experience was gained in the SWAN or new information came to light about a historical photograph. Final selection of photo point locations for the photo-monitoring network was an iterative process that depended on the extent of historical photography available, what monitoring targets were already captured or missing in the compilation of historical photographs, the logistics and feasibility of accessing the original vantage point in the field, and the quality of the historical photograph.

The design of the photo-monitoring network included (1) identifying and prioritizing features of interest (e.g., glaciers, floodplains, plant succession), (2) distributing the monitoring sites and specifying reacquisition frequency, (3) developing monitoring protocols, and (4) refining database management routines.

As historical photographs were acquired and their monitoring potential evaluated, the photo point locations of high and moderate repeat potential photographs were incorporated into a GIS geodatabase in *ArcView* (9.x). The geodatabase is an Access database readable and editable in both *ThumbsPlus* and *ArcView*, providing information about each photograph along with its spatial attributes. Geographic locations were estimated to the nearest hundredth decimal degree of latitude and longitude based on original photograph captions and/or geographic features evident in the photographs. Estimated monitoring site locations were then entered into the geodatabase over a *Landsat* imagery layer. Historical photographs at each site were hyperlinked into the geodatabase to facilitate viewing of the images. To make geodatabase functionality more widely available, an *ArcReader* file can be constructed to provide users with a simple GIS interface that allows them to click on a map location and view associated photographs, change the appearance of the data, and perform spatial and attribute queries using the same files useable in *ThumbsPlus* or *ArcView*.

Repeat Photography

Acquisition of new photography involved (1) acquiring new photography at sites that have historical photography to establish a temporal record, and (2) acquiring photography at new locations to increase the spatial dimensions of the record and to document high-priority landscape features. Repeat photography was conducted to duplicate to the greatest extent possible the location and orientation of historical photography, using methods described by Hall (2002). Tripods were used where appropriate to aid in duplicating original camera position and orientation, but in some cases cameras were handheld, or placed directly on rocks or on the ground when indicated by historical photographs. In cases where the vantage point used in original photography could not be precisely triangulated or no longer exists (e.g., a river cutbank), an alternative vantage point was selected to approximate the original as closely as possible. When a helicopter was used for photo point access and there was no nearby location to land, the vantage point was approached as closely as possible and the historical photo repeated from the hovering helicopter. In instances where original vantage points were overgrown by trees, trees were climbed in order to obtain general landscape views. During field visits, the geographical coordinates for each photo-monitoring site were recorded using a 12-channel GPS (*Garmin* eTrex Legend or *Garmin* 76Cx) to facilitate repeated monitoring. Other information such as date, observer, camera height, azimuth, and dominant plant species were recorded. The locations of photographic vantage points were not staked in the field, but in some cases close-up photographs illustrating the precise camera position were taken.

Repeat photography under Phase 3 was initiated in July and August 2004 in three SWAN units: Lake Clark, Katmai, and Aniakchak. In Lake Clark, Torre Jorgenson (ABR) and Alan Bennett (NPS) used a helicopter to access photo points distributed throughout the park, 28–30 July. In Katmai, Gerald Frost (ABR) and Tahzay Jones (NPS) worked on the ground to access photo points in the vicinity of the Valley of Ten Thousand Smokes, upper Knife Creek, Mageik Creek, and the middle Katmai River, 31 July–7 August. In Aniakchak, Amy Miller and Alan Bennett (NPS) worked on the ground to access photo points at Aniakchak Caldera and Aniakchak Bay, 17-21 July. In 2005, Torre Jorgenson and Alan Bennett used a helicopter to access additional photo points distributed throughout Katmai, 13–17 June. Gerald Frost and Tahzay Jones worked on the ground to access photo points in the King Salmon area, 22–24 July, but persistent poor weather prevented access to photo points clustered in the vicinity of the Katmai River and Katmai Bay. In 2006, Gerald Frost, Dorothy Mortenson (NPS), Ryan Rumelhart (NPS), and two volunteers worked on foot and with a raft to access photo points at Aniakchak from Aniakchak Caldera to Aniakchak Bay after using a floatplane to access Surprise Lake. Digital cameras were used at all study areas. Specific camera equipment used in 2004 was *Olympus* C-750 in Lake Clark and Aniakchak and *Nikon* Coolpix 5700 in Katmai. In 2005, Torre Jorgenson and Alan Bennett used a *Kodak* DCS Pro SLR-C, while Gerald Frost and Tahzay Jones used a *Nikon* Coolpix 5700. In 2006, Gerald Frost and Dorothy Mortenson used a *Nikon* Coolpix 5700, a *Canon* Powershot A620, and *Olympus* C-750.

Additional repeated photographs for Aniakchak Caldera were obtained from the NPS Field Office in King Salmon, AK that had been acquired by Tahzay Jones in August 2005.

Results

Compilation of Historical Photographs

A total of 1099 historical photographs were acquired for four of the five SWAN units: Aniakchak (204), Katmai (654), Kenai Fjords (50), and Lake Clark (191) (Table 1, Figures 2–5). Of these, 785 photographs date from 1930 or earlier, with the oldest dating to 1895. No photographs useful in documenting landscape change in Alagnak Wild River were identified.

Particularly important projects related to the historical photograph collection include National Geographic Society expeditions led by Robert Griggs (1922), USGS field surveys (Grant and Higgins 1909, Martin 1912, Smith 1925, Capps 1930, 1931), and expeditions led by Bernard Hubbard (1935). Important photographs for use in assessing landscape change in Aniakchak include those from Walter Smith (1922), Bernard Hubbard (1930–1932), and Keith Trexler (1972–1973) (Table 1). For Katmai, important collections are from Ralph Stone (1904), Timothy Stanton (1904), George Martin (1912), Robert Griggs and associated expedition members (1915–1919), Walter Smith (1922), Kirtley Mather (1923), Charles Yori (1923), Bernard Hubbard (1928–1935), and Victor Cahalane (1953–1954). For Kenai Fjords, important collections are from Ulysses Grant (1909) and D. Higgins (1909). For Lake Clark, important collections are from Fred Moffit (1920–1921), Stephen Capps (1927–1929), and Arthur Grantz (1950).

Monitoring Network Development

During the screening process the primary and secondary subjects of the photographs were grouped into 12 broad subject classes (Table 2). The compilation of photographs indicates that the most common primary subjects are plant succession (381 photographs), floodplains (179), and glaciers (129).

The repeat potential of each historical photograph was assessed as high, moderate, or low. Of the photographs that were not repeated in 2004–2006, 158 have high potential, 343 have moderate potential, and 302 have low potential. Remaining high potential photographs are in Katmai (113), Aniakchak (8), Kenai Fjords (25), and Lake Clark (12).

The final aspect of the network development was the assessment of logistical requirements for accessing the photo-monitoring sites. These requirements vary widely by park. In Lake Clark, the photograph locations are highly dispersed and best accessed by helicopter, requiring three days of good weather to complete. In Katmai, the photographs were grouped into four sets: (1) a dense cluster of foot-accessible sites in and around the Valley of Ten Thousand Smokes requiring about five days of good weather to complete, (2) a small cluster of sites accessed by canoe along the

Table 1. Number of photographs by year, photographer, and park for historical photographs compiled for the Southwest Alaska Network Parks[a].

Year	Photographer	ANIA	KATM	KEFJ	LACL	Total
1895	Purington, Chester W.		2		1	3
1899	Gilbert, Grove Karl		2	3		5
1904	Stanton, Timothy W.		7		2	9
	Stone, Ralph W.		12	1		13
1906	Martin, George C.			1		1
1909	Grant, Ulysses S.			24		24
	Higgins, D.F.			19		19
	Katz, Frank J.				7	7
1912	Martin, George C.		21		2	23
1914	Smith, Philip S.				1	1
1915	Fulton, B.B.		14			14
	Griggs, Robert F.		8			8
1916	Church, D.B.		24			24
	Griggs, Robert F.		5			5
1917	Church, D.B.		59			59
	Folsom, Lucius G.		7			7
	Griggs, Robert F.		41			41
	Hagelbarger, Paul R.		12			12
	Maynard, Clarence F.		2			2
	Sayre, Jasper D.		10			10
	Shipley, J.W.		8			8
	unknown		22			22
1918	Hagelbarger, Paul R.		28			28
	Sayre, Jasper D.		33			33
1919	Basinger, A.J.		1			1
	Griggs, Robert F.		29			29
	Hagelbarger, Paul R.		42			42
	Helt, Richard E.		2			2
	Henning, William L.		26			26
	Jones, F.I.		4			4
	Kolb, Emery C.		14			14
	Sayre, Jasper D.		25			25
	unknown		1			1
1920	Moffit, Fred H.				21	21
1921	Moffit, Fred H.				1	1
	unknown				1	1
	Vreeland, F.K.				1	1
1922	Sargent, Rufus H.	1				1
	Smith, Walter R.	17	28			45
1923	Mather, Kirtley F.		22			22
	Russell, Ray		1			1
	Yori, Charles		13			13
1927	Capps, Stephen R.				32	32
1928	Capps, Stephen R.				41	41
	Hubbard, Bernard R.		5			5

Table 1. Continued.

Year	Photographer	ANIA	KATM	KEFJ	LACL	Total
1929	Capps, Stephen R.				12	12
	Hubbard, Bernard R.		19			19
	unknown				1	1
1930	Griggs, Robert F.		2			2
	Hubbard, Bernard R.	42	1			43
	Moses, Helena				1	1
1931	Hubbard, Bernard R.	28	5			33
1932	Capps, Stephen R.		5	2		7
	Hubbard, Bernard R.	43				43
1935	Dickson, Roy				1	1
	Hubbard, Bernard R.		40			40
1936	Hubbard, Bernard R.		1			1
1940	Park, Bill				1	1
	unknown				1	1
1947	Diederich, Leo		3			3
1948	Miller, Don J.				7	7
1949	Miller, Don J.				2	2
1950	Grantz, Arthur				20	20
	unknown		1			1
1953	Cahalane, Victor H.		14			14
1954	Cahalane, Victor H.		8			8
	Curtis, Garniss		3			3
	Schaller, George B.		17			17
	Straty, Dick		1			1
1972	Moorehead, Bruce	2				2
	Nichols, Robert	1				1
	Swem, Ted				1	1
	Trexler, Keith	12			5	17
	Williams, M. Woodbridge	1			10	11
1973	Trexler, Keith	14				14
	unknown	3				3
	Vaughn, Phil	1				1
	Waldrop, Bob				2	2
	Williams, M. Woodbridge	17			1	18
1974	Bradley, Philip				6	6
	Stondall, Edward N.	1				1
	Williams, M. Woodbridge	1				1
1975	Jones, Randy				1	1
	Proenneke, R.				1	1
	Resor, Bill				4	4
	Root, Ralph	3				3
	Stondall, Edward N.	2				2
	unknown	2				2
1976	Follows, Donald S.	10				10
	Malik, M.	1				1
	Root, Ralph	2				2
1979	Miller, T.		1			1

Table 1. Continued.

Year	Photographer	ANIA	KATM	KEFJ	LACL	Total
1980	Till, A.				1	1
1982	Nye, C.		2			2
1985	Miller, T.	1				1
1990	Gardner, C.				2	2
	Iwatsubo, G.		1			1
	Miller, T.				1	1
1992	Neal, C.	1				1
Grand Total		204	654	50	191	1099

[a] ANIA = Aniakchak National Monument & Preserve, KATM = Katmai National Park & Preserve, KEFJ = Kenai Fjords National Park, LACL = Lake Clark National Park & Preserve; no historical photographs have been acquired for Alagnak National Wild River.

Table 2. Number of historical photographs by primary subject and park compiled for the Southwest Alaska Network of National Parks.

	Park Unit[a]				
Primary Subject	Aniakchak	Katmai	Kenai Fjords	Lake Clark	Total
Avalanche Chute	2				2
Coastal	12	49	2	14	77
Floodplain	38	105		36	179
Glacier		58	46	25	129
Human Disturbance	1	3		1	5
Lacustrine	21	40		18	79
Landslides	3	35		8	46
People	1	12		1	14
Plant Succession	84	271	2	24	381
Shrub Expansion	3	8		34	45
Tree Expansion		36		28	64
Volcanism	39	37		2	78
Total	204	654	50	191	1099

[a] No historical photographs have been acquired for Alagnak National Wild River.

Naknek River near Naknek Rapids requiring one day to complete, (3) a fairly dense collection of photographs concentrated along the Katmai coast requiring three days of helicopter access in good weather, and (4) a set of highly dispersed photographs in the western portion of the park requiring one day of helicopter access. In Aniakchak, the photographs were grouped into two sets: (1) a dense cluster of foot-accessible sites around the Aniakchak Caldera requiring six good-weather days to complete, and (2) a dispersed set of photographs along the Aniakchak River requiring about four good-weather days to complete by floating down the river. It was determined that a handful of highly dispersed Aniakchak photographs in the Meshik Lake, Ray Creek, and Kujulik Bay areas would best be repeated opportunistically with a helicopter in the course of other studies. In summary, the photographs require an approximate total of seven days of helicopter access and 16 days of foot/raft/canoe access in good weather. Substantial additional time is required to allow for travel and bad weather days, particularly at Aniakchak.

Repeat Photography

A total of 294 historical photographs have been repeated by ABR and NPS personnel in three SWAN units: Katmai (134 photographs), Lake Clark (59), and Aniakchak (101) (Table 3, Figures 6–9). A selection of historical and repeated photo pairs is provided in Figures 10-189; informal place names in quotation marks used for Aniakchak follow Neal et al. (2001). In addition, 39 new photographs were acquired at 18 new photo-monitoring sites in Katmai and 218 new photographs were acquired at 33 new photo-monitoring sites in Aniakchak (Table 3). Kenai Fjords was not visited because repeat photography of tidewater glaciers was conducted during 2004-2005 by Bruce Molnia (USGS). These photos will eventually be incorporated into the SWAN photo-monitoring database.

Table 3. Number of repeated and new photographs by primary subject and park compiled for Southwest Alaska Network of National Parks.

Primary Subject	Aniakchak		Katmai		Lake Clark		Total		
	Repeat	New	Repeat	New	Repeat	New	Repeat	New	Both
Avalanche Chute	1						1		1
Coastal	5	16	5	7	2		12	23	35
Floodplain	16	47	15	4	10		41	51	92
Glacier			19	8	4		23	8	31
Lacustrine	11	2	6	3	9		26	5	31
Landslides	2	17	8		3		13	17	30
Plant Succession	53	83	59	16	3		116	99	214
Shrub Expansion	2	51	2	1	12		15	52	68
Tree Expansion			12		16		28		28
Volcanism	11		8				19		19
Human Disturbance		2						2	2
Total	101	218	134	39	59		294	257	551

Based on our experience and changes that we have seen in the photography, we recommend that photo-monitoring sites be re-photographed at ten year intervals. However, photos should be repeated as soon as possible following any large volcanic, seismic, or other disturbance event. Also, we recommend that photos be repeated opportunistically at hard-to-reach monitoring sites whenever trained personnel are in the area. Although all the photographs potentially could be acquired in one year, we anticipate that it would be more reasonably done over a two-year period.

Discussion

The primary purpose of establishing the photo-monitoring network is to assess landscape change. The compilation of 1099 historical photographs and the repetition of 294 of the photographs provide a comprehensive network for a repeat-photography monitoring program in all SWAN units, except Alagnak Wild River. All major biological and geomorphic thematic components are well represented across the park network by the photographs. Below we provide a brief discussion of the primary changes in the landscape that are evident from the photo-monitoring network. The photographs also provide an important archive of information for a more quantitative sampling approach.

Plant Succession

There are many sources of disturbance in the SWAN that create conditions facilitating plant colonization and succession, including volcanism, glaciation, floodplain dynamics, coastal dynamics, and fire. In most cases, changes in the dominant vegetation at photo-monitoring sites can be readily identified after repeat photography. By describing vegetation at the time photographs are repeated in the field, changes in co-dominant plants can also be determined in the future.

At Katmai, many photo-monitoring sites reveal patterns of primary and secondary succession following a cascade of disturbance events triggered by the 1912 eruption of Novarupta. Adjacent to the eruption site, The Valley of Ten Thousand Smokes encompasses a very young, entirely inorganic surface formed by the ground-hugging flow of 1912 pyroclasts. Comparing recent photography in the Valley of Ten Thousand Smokes with an extensive collection of historical photographs confirms that the pace of primary succession there has been very slow (Figures 10–15). The first colonizing vascular plants were not observed until 1930 (Griggs 1933) and vegetation remained very sparse at almost every photo-monitoring site visited in 2004. In the absence of stabilizing vegetation, the Valley's unconsolidated ash and pumice surface has undergone widespread gully erosion. Primary succession is conspicuous only in sheltered microsites, particularly in a handful of extinct fumarole pits near Novarupta where soil chemistry and other conditions appear to be relatively favorable (Figure 16). Primary succession also is relatively advanced in areas near the Knife Creek Glaciers, although it is not clear why (Figures 17–20). Willows (primarily *Salix barclayi* and *S. alaxensis*) and graminoids (primarily *Luzula* spp., *Carex mertensii,* and *Calamagrostis canadensis*) are the most common new vascular plants on 1912 pyroclasts. Alder (*Alnus* spp.), however, is virtually absent from 1912 pyroclasts, even though it is abundant regionally and is common in early succession on new surfaces exposed by glacial retreat.

Ecosystems near the Katmai coast that were disturbed primarily by ashfall in 1912 have generally recovered at a much faster pace (Figures 21–55). Historical photographs of a series of bays and coastal mountains along the rugged coastline of Shelikof Strait record a largely barren landscape devastated by ashfall, with maximum ash depths estimated at over 2 m (Griggs 1922). However, numerous photographs dating as far back as 1919 show scattered, live tall shrub thickets on many of the steeper mountain slopes. These thickets almost certainly represent 1912 vegetation that survived where thick ash deposits did not persist. In this way, the recovery of Katmai's coastal vegetation probably reflects a combination of secondary and primary successional processes. Today, the coastal mountains of Katmai have largely revegetated, although some barren pockets remain where thick accumulations of tephra have persisted.

Elsewhere in Katmai, relatively subtle disturbance appears to have affected lichens. A series of photographs taken in 1919 from rocky outcrops near Lake Grosvenor reveals virtually no crustose lichen cover on granitic boulders (Figures 82–84). Today, xerophytic crustose lichens (chiefly *Umbillicaria* spp.) are conspicuous on these boulders. Given the broad environmental tolerances and circumpolar distribution of these lichens, it is likely that the appearance of lichens represents recovery after disturbance rather than elevational or geographical expansion. A possible cause of lichen mortality may have been acid rain that followed the 1912 eruption.

At Aniakchak, successional processes following the eruption of 1931 have resulted in many conspicuous changes in the young volcanic landscape of Aniakchak Caldera. Large amounts of tephra buried much of the original ground surface and left an extensively barren landscape. However, in contrast to The Valley of Ten Thousand Smokes, vegetation cover has increased markedly at numerous photo-monitoring sites in Aniakchak Caldera, although patterns of succession vary locally with riverine and lacustrine areas having generally recovered the fastest. In a series of sheltered coves along the western shoreline of Surprise Lake, willows, forbs, and graminoids form a nearly complete ground cover in sheltered gullies (Figures 139–145). Here, photo-monitoring sites that were first photographed in 1930 suggest that current vegetation cover approximates or even exceeds what was present prior to the 1931 eruption. Vegetation recovery after tephra burial is also relatively advanced on alluvial flats lining the northwestern and southeastern shores of the lake (Figures 146–156), and on portions of the upper Aniakchak River floodplain just outside the caldera (Figures 157–158). On extensive uplands between Surprise Lake and the base of Vent Mountain, beach ryegrass (*Leymus mollis*) is the primary pioneering species (Figures 159–164). Beach ryegrass appears to stabilize the coarse, inorganic tephra of the area much as it does the coastal dunes and young riverine surfaces with which it is usually associated elsewhere. Several photo-monitoring sites that supported sparse ryegrass meadows in the 1970s now support much more diverse plant communities. Beach ryegrass has also colonized many new sites since the 1970s, although large portions of the caldera remain barren. In the southwestern portion of the Caldera near Birthday Pass, primary succession is occurring at a much slower pace (Figures 165–173). Here, Piper's woodrush (*Luzula piperi*) is the most common colonizing vascular plant and beach ryegrass is virtually absent, although the reasons for this shift are not clear. The slower pace of primary succession in the southwest caldera area probably reflects its higher elevation and close proximity to centers of 1931 volcanism. In uplands of the southeastern caldera, patterns of vegetation recovery vary Figures 174–175). Photo-monitoring in the caldera indicates that although the colonization of barren sites tends to occur at a slow pace, vegetation expansion and diversification after colonization can occur relatively quickly. Numerous new photo-monitoring sites established in the caldera in 2006 will allow future documentation of succession in a variety of habitats.

After glacial retreat, vegetation colonization has been dramatic in coastal areas of the SWAN, but less so at higher elevation inland sites. At the Spotted Glacier (Figure 70) in Katmai, the land exposed by glacial retreat has been colonized by a nearly 100% shrub canopy of alder with scattered cottonwood and spruce trees overtopping the shrubs. The Shamrock Glacier in Lake Clark has receded ~2 km from its 1928 position near its terminal moraine, and the older portions of the moraine have been vigorously colonized by cottonwood (*Populus* spp.), alder, and Drummond's mountain-aven (*Dryas drummondii*) (Figure 115). In contrast, only ~10% of the land exposed since 1917 by glacial retreat in an alpine valley adjacent to the southwest corner of the Valley of Ten Thousand Smokes has become vegetated (Figure 73). Similarly, exposed glacial moraine evident in 1928 remained essentially barren in 2004 at a glacial valley at the head of Another River in Lake Clark (Figure 106).

Successional response to coastal changes has been dramatic in some areas following seismic uplift associated with the 1964 earthquake. At Chinitna Bay in Lake Clark, barren mudflats photographed in 1909 have been colonized by semihalophytic graminoids after ~ 2m of uplift elevated them above the intertidal zone (Figure 99).

Plant succession after fire was recorded in only one area, in part because fires are relatively infrequent in most of the SWAN. Near Tanalian Falls and Kontrashibuna Lake in Lake Clark, paper birches have formed a closed canopy where a fire burned all but scattered large white spruce (*Picea glauca)* trees not long before 1909 (Figures 114 and 115). A small, human-caused fire in the Meshik Lake area of Aniakchak in 2006 was not visited in the course of this project, although photographs taken by NPS and BLM personnel at the site should provide baseline information permitting photo-monitoring of post-fire succession there.

Tree Expansion

At Katmai, geographical treeline expansion was documented at sites along the Naknek River near King Salmon (Figures 74–78). Several photo-monitoring sites that were first photographed in 1919 now support greatly increased cover of white spruce (*Picea glauca*) and Kenai birch (*Betula kenaica*). In northern Lake Clark, white spruce trees have made significant elevational expansions at several montane sites over the last ~75 years, evidenced by a collection of historical photographs taken in1928–1929 (Figures 117–131). Although local treeline elevations vary substantially and some monitoring sites do not indicate recent tree expansion, most sites at elevations at or below ~850 m that already supported at least some Krummholz spruce trees in 1928–1929 now support much larger and more numerous trees. None of the1928–1929 photographs show any evidence of a recent fire or other disturbance event at these sites, indicating that the new trees represent elevational treeline expansion rather than recovery after disturbance. However, in alpine tundra areas well above treeline (~850 m or higher) in montane landscapes of Lake Clark, little change in vegetation is apparent (Figures 100–109). Although the elevational and geographical expansion of trees in portions of SWAN probably relates to a combination of changing environmental, biogeographical, and other factors, it appears likely that increased mean annual temperatures in southwestern Alaska since the end of the Little Ice Age in the mid-1800s have been a contributing factor.

Shrub Expansion

Alder-dominated tall shrub thickets have expanded to higher elevations and developed increased canopy coverage at several monitoring sites first photographed in 1928–1929 in northern Lake Clark (Figures 132–133). Tall shrubs also have become much more abundant at the sites where tree expansion was documented. As with treeline, however, the elevational limit of tall shrubs in Lake Clark shows much local variation and not all monitoring sites indicate dramatic expansion. In northern Katmai, dramatic elevational expansion of tall shrubs also was documented at several monitoring sites (Figures 79–88). Expansion is particularly evident in uplands near Lake Grosvenor, which were first photographed in 1919. Oblique views from granitic ridges that indicated <50% coverage of tall shrubs in 1919 now indicate coverage of ~75% or more. Although the Lake Grosvenor area received light ashfall during the 1912 eruption of Novarupta, mortality of shrubs is not evident in the 1919 photographs.

At Aniakchak, historical photography useful in assessing shrub expansion is limited. However, shrub expansion was conspicuous in uplands in the upper Aniakchak River valley at several photo-monitoring sites first photographed only ~30 years ago (Figures 176–178). Shrub expansion was not indicated at several coastal sites. Future photo-monitoring at numerous new sites established along the Aniakchak River will facilitate assessments of shrub expansion in the future.

Volcanism

In Katmai, photo-monitoring sites in the Valley of Ten Thousand Smokes reflect very little change in volcanic features since 1916 other than the cessation of vigorous steam venting and fumarolic activity. In the absence of stabilizing vegetation, gully erosion has slightly modified the surface of the Valley of Ten Thousand Smokes. Continued volcanic activity in the region, however, is apparent at a photo-monitoring site at Mageik Creek, which was first photographed in 1919. Here, a series of lava flows originating from Trident Volcano entered the creek valley and shifted portions of the active floodplain of Mageik Creek in the 1950s (Figure 92). At Aniakchak, photo-monitoring sites throughout the Aniakchak Caldera area indicate extensive tephra deposition following the 1931 eruption. However, no significant changes in volcanic features are evident since volcanism in 1931.

Glaciers

In both Katmai and Lake Clark, photo-monitoring sites indicate a trend of glacial retreat in southwestern Alaska over the past century. Important historical photographs taken from 1895–1904 in the Cape Douglas area record the positions of several large glaciers not long after the end of the Little Ice Age (c.1350–1850), a period of moderate global cooling. All of the glaciers rephotographed in the Cape Douglas area, including the Spotted, Fourpeaked, and several large unnamed glaciers, have retreated considerably (Figures 65–70). In Lake Clark, the Tanaina Glacier at Lake Clark Pass retreated ~1.4 km from 1940 to 1999, with most of the retreat occurring between 1954 and 1979 (Figure 138). Just outside Lake Clark, the Shamrock Glacier retreated ~2 km since 1928 (Figure 116). The only glaciers where recent retreat was not indicated were in areas just east of Novarupta. The Knife Creek Glaciers, a small cirque glacier, and a large unnamed glacier at the head of the Katmai River have changed little since they were first photographed in the mid-1910s (Figures 71–72). Historical photographs confirm that these glaciers received heavy ashfall following the 1912 eruption. The insulating effect of these ash deposits has probably reduced ablation rates of these glaciers considerably. In contrast, an alpine glacier adjacent to the Valley of Ten Thousand Smokes that received relatively light ashfall has retreated significantly (Figure 73). At Aniakchak, photo-monitoring of several small, "hanging" alpine glaciers along the southern inner caldera wall has thus far been inconclusive due to the persistence of seasonal snow cover at the times of photography.

Landslides

In Katmai, seismic activity during the 1912 eruption of Novarupta triggered large landslides in the upper Katmai River valley, Katmai Canyon, and the Martin Creek valley. Colluvial deposits in the upper Katmai River valley near Noisy Mountain have changed very little since they were first photographed in 1917 (Figure 93). Landslide colluvium from the southern slopes of Mt. Katmai temporarily dammed the Katmai River in Katmai Canyon, although people did not visit this area until shortly after the dam failed in 1915. Photo monitoring sites overlooking this colluvial deposit reveal no dramatic changes, although the Katmai River has eroded portions of the deposit since 1917 (Figure 94). Unlike the colluvial features of the Katmai River valley, vegetation recovery on the Mageik Landslide in the Martin Creek valley is at an advanced stage and consequently much of the colluvial surface is now obscured (Figures 95–97). However, the colluvium itself has not been significantly modified by fluvial or other processes since its deposition. In Lake Clark, remarkably little change is apparent in several alpine rockslides and talus slopes near Merrill Pass, which was first photographed in 1928 (Figure 13).

At Aniakchak, photo-monitoring indicates a recent surge in landslide activity in the vicinity of Black Nose, which forms the south wall of The Gates. In The Gates, large boulders in and near the channel of the Aniakchak River are far more numerous in recent photos than in photos from the early 1930s and 1970s. Many of the new boulders were apparently deposited in 2005, when NPS personnel in the caldera reported an earthquake and landslide activity on the south side of The Gates. In 2006, several more new boulders were observed in The Gates (Figure 179). Inside the caldera, several large boulders have appeared on a colluvial talus slope below the summit of Black Nose since the site was first photographed in 1922.

Floodplains

Repeated photographs of floodplains confirm that fluvial processes continue to be important agents of disturbance in the SWAN, particularly on the broad floodplains of glaciated drainages of Katmai and Lake Clark where sediment load is high and channel migration is frequent. In Lake Clark, floodplain sites first photographed along the Tlikakila River (1909), Johnson River (1920), and Stony River (1928) continue to be dominated by barren gravel (Figures 110–113). At these sites, vegetation on islands and terraces documented in historical photography has since been disturbed. In contrast, some surfaces that were barren in historical photography have been colonized by vegetation. The positions of fluvial features such as active channels and mid-channel bars have also changed markedly. Glacial rivers and streams in Katmai near Cape Douglas that were first photographed from 1895–1904 reflect similar changes (Figure 56). In contrast, the deeply incised floodplain of the Tanalian River near Tanalian Falls appears virtually unchanged since it was first photographed in 1909 (Figure 114).

In Katmai, a variety of recent changes are evident in drainages that were disturbed by landslides, ashfall, and/or flooding associated with the eruption of Novarupta in 1912 (Figures 57–64). For example, at Katmai Canyon, a large landslide on the southern slopes of Mt. Katmai dammed the upper Katmai River for about 3 years, forming a large but short-lived lake. In 1915, dam failure resulted in a large flood event that retransported large volumes of colluvium to the lower floodplain. The presence of vegetated terraces on portions of the constricted canyon floodplain indicates that the Katmai River has cut through much of the 1915 colluvium since it was first photographed in 1916. An immense volume of retransported colluvial and volcanic material has filled the broad floodplain of the lower Katmai River, resulting in a heavily braided and continually migrating network of channels. Monitoring locations near the abandoned Katmai village site indicate that channel migration and associated deposition of alluvium has destroyed any remaining traces of the village (Figure 63).

At Aniakchak, channel migration and associated primary succession were detected at several photo-monitoring sites on the Aniakchak River floodplain, primarily on the upper river (Figures 180-186). Several new photo-monitoring sites were also established in 2006 along the middle and lower Aniakchak River to track floodplain dynamics and associated plant succession in those areas.

Lacustrine Processes

In Katmai, a fissure lake formed in the upper Valley of Ten Thousand Smokes in 1912 has drained since 1917 (Figure 89). In contrast, the shoreline of a small lake formed by the Mageik Landslide at about the same time has not changed significantly (Figure 90). Much of the eastern end of the Iliuk Arm near the mouths of the Ukak and Savonoski Rivers has been filled by ash-rich sediment since 1919 (Figure 91). A dramatic increase in sediment input by the Ukak River has likely occurred since 1912 as this river drains areas that were severely affected by ashfall and pyroclastic flows, including the Valley of Ten Thousand Smokes. At other large glacial lakes of the SWAN, such as Turquoise Lake in Lake Clark (Figure 100), little change in lake levels has been photo documented.

At Aniakchak, the northwestern and southeastern shorelines of Surprise Lake have undergone substantial changes since the 1930s that indicate a modest reduction to the lake’s areal extent (Figures 187-190). The change is most likely due to alluvial retransportation of 1931 tephra, not to changes in water depth. Minor shoreline changes seen elsewhere at Surprise Lake appear to be due to seasonal depth fluctuations that reflect the amount of snowmelt entering the lake.

Coastal Dynamics

Change along the coast varies by shoreline type, with little change to rocky shores and at times dramatic change to tidal flats. Very little recent change has occurred to rocky coastlines at Cape Douglas (Figures 97–98), and Fossil Point in Tuxedni Bay (Figure 137). However, seismic uplift associated with the 1964 earthquake raised intertidal mudflats about 6 feet along Chinitna Bay at

Lake Clark. Here, barren mudflats photographed in 1909 have been colonized by semihalophytic graminoids. However, a nearby coastal meadow that was already above the intertidal zone in 1948 reflects little change (Figure 135–136). At Aniakchak, change to coastal landforms was limited at one site at Kujulik Bay, but a range of recent changes is apparent at Aniakchak Bay (Figures 191-195).

Summary and Conclusions

To assess landscape changes in the Southwest Alaska Network (SWAN) of National Parks, 1099 historical photographs dating as far back as 1895 were acquired for Lake Clark (191), Katmai (654), Aniakchak (204), and Kenai Fjords (50). A digital archive structure and *ThumbsPlus*-Access database were developed to compile information about the photographs and prioritize them for repeat photography. The photographs are stored as high-resolution (~10 Mb tiff) images for archiving and research, and low-resolution (~300 kb jpg) images for rapid review and broader distribution. The primary subjects of the photographs have been categorized as volcanism, glacier, floodplain, colluvium-landslide, avalanche chute, lacustrine, coastal, plant succession, shrub expansion, tree expansion, people, and human disturbance. During 2004-2006, 294 photographs were repeated in Lake Clark (59), Katmai (134), and Aniakchak (101, including photographs taken by other park projects), and 254 photographs were taken of new scenes in Katmai (39) and Aniakchak (215).

In comparing the old and recent photographs, it is evident that a variety of changes associated with successional and geomorphic processes have occurred within the SWAN. Volcanism in Katmai and Aniakchak initiated a cascade of disturbance events that created extensive barren landscapes over the last century. Succession has proceeded at a faster pace at Aniakchak Caldera than The Valley of Ten Thousand Smokes, although in general primary succession has been slow in both locations outside of favorable microsites. Most glaciers monitored in the SWAN have shown dramatic retreat since the early 1900s, with newly exposed surfaces becoming rapidly vegetated by tall shrubs and trees at low elevations, but remaining sparsely vegetated at higher elevations. Floodplains have continued to be active over time, creating barren areas, while other stable, inactive areas have been colonized by vegetation. Photographic evidence of landslides was uncommon, but several large slides were documented at Katmai in association with the eruption of Novarupta in 1912 and vegetation recovery has occurred at vastly different rates on these colluvial surfaces. In coastal areas, little change was evident along rocky shorelines, but some dramatic colonization by halophytic vegetation occurred on tidal flats that were uplifted during the 1964 earthquake at Chinitna Bay and recent changes in coastal geomorphology are evident at Aniakchak Bay. Expansion of trees and shrubs was observed in western Katmai, and altitudinal increase in treeline was observed at many locations in Lake Clark and Katmai. Shrub expansion also appears to be occurring in interior uplands of Aniakchak, but not in coastal areas. While the photographic archive provides an initial quick assessment of landscape changes that have occurred over the last century, the archive of historical and new photo-monitoring sites could be used to more rigorously quantify these changes.

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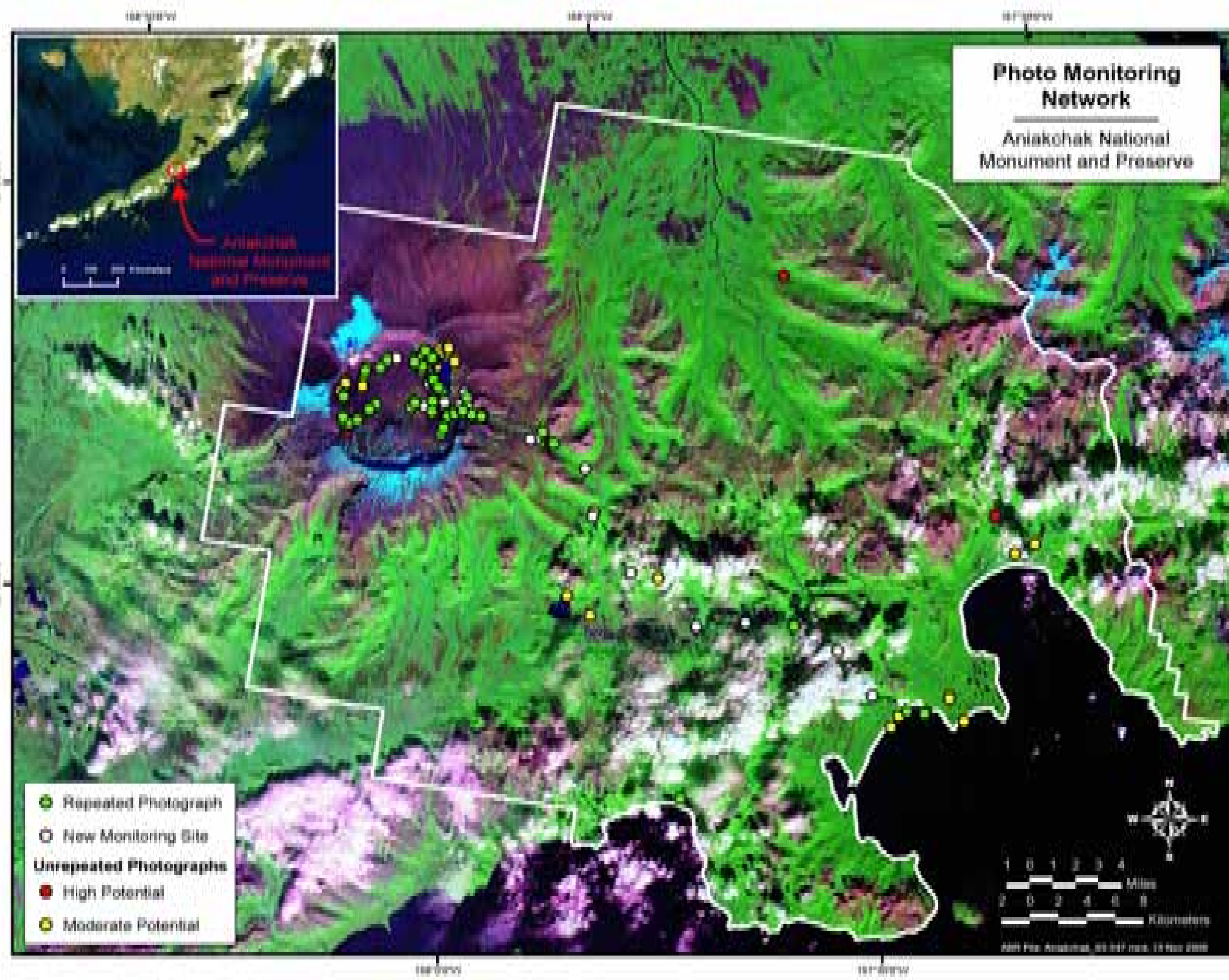

Figure 2. Photo-monitoring network developed for Aniakchak National Monument and Preserve. Location of unrepeated photos are estimated.

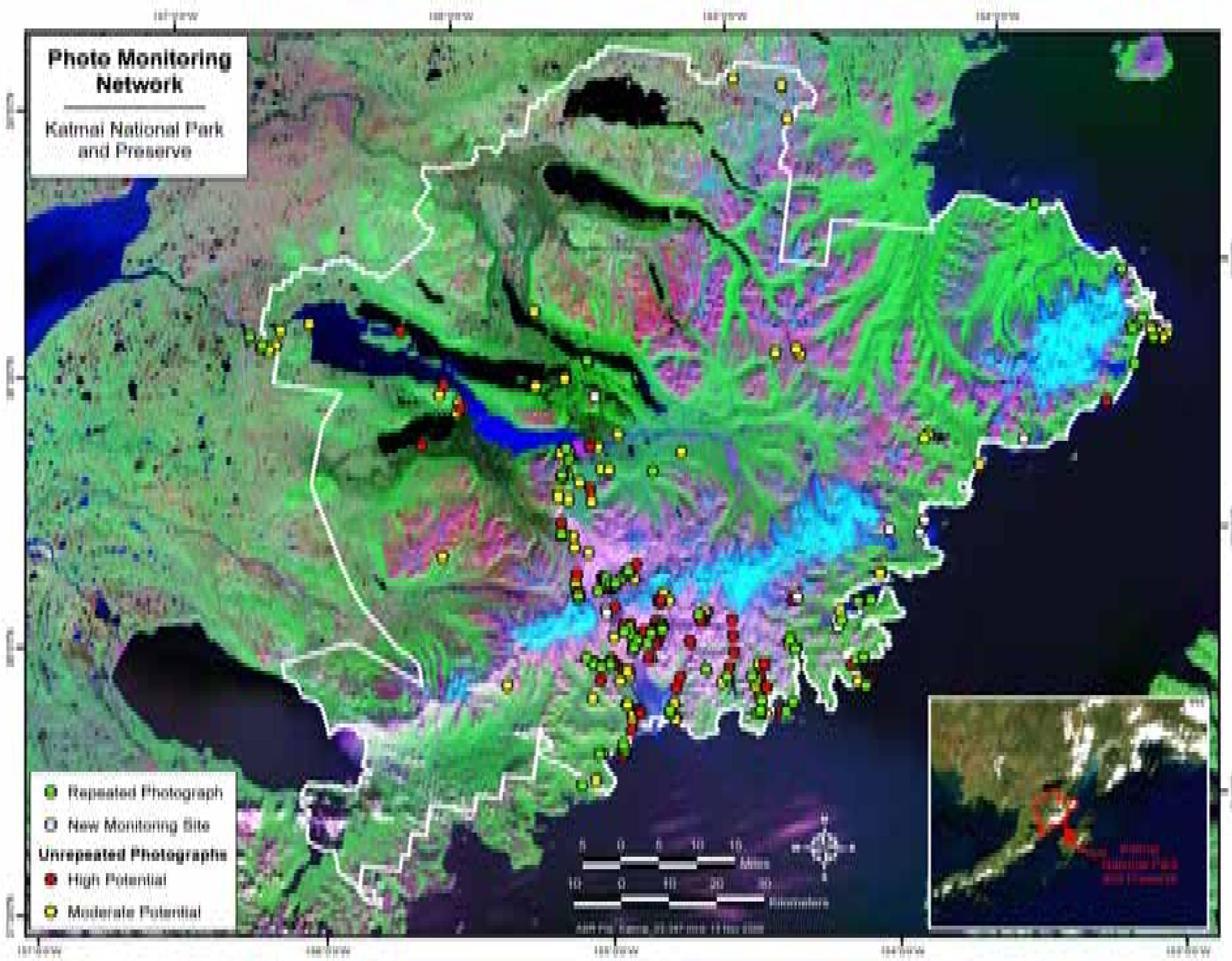

Figure 3. Photo-monitoring network developed for Katmai National Park and Preserve. Location of unrepeated photos are estimated.

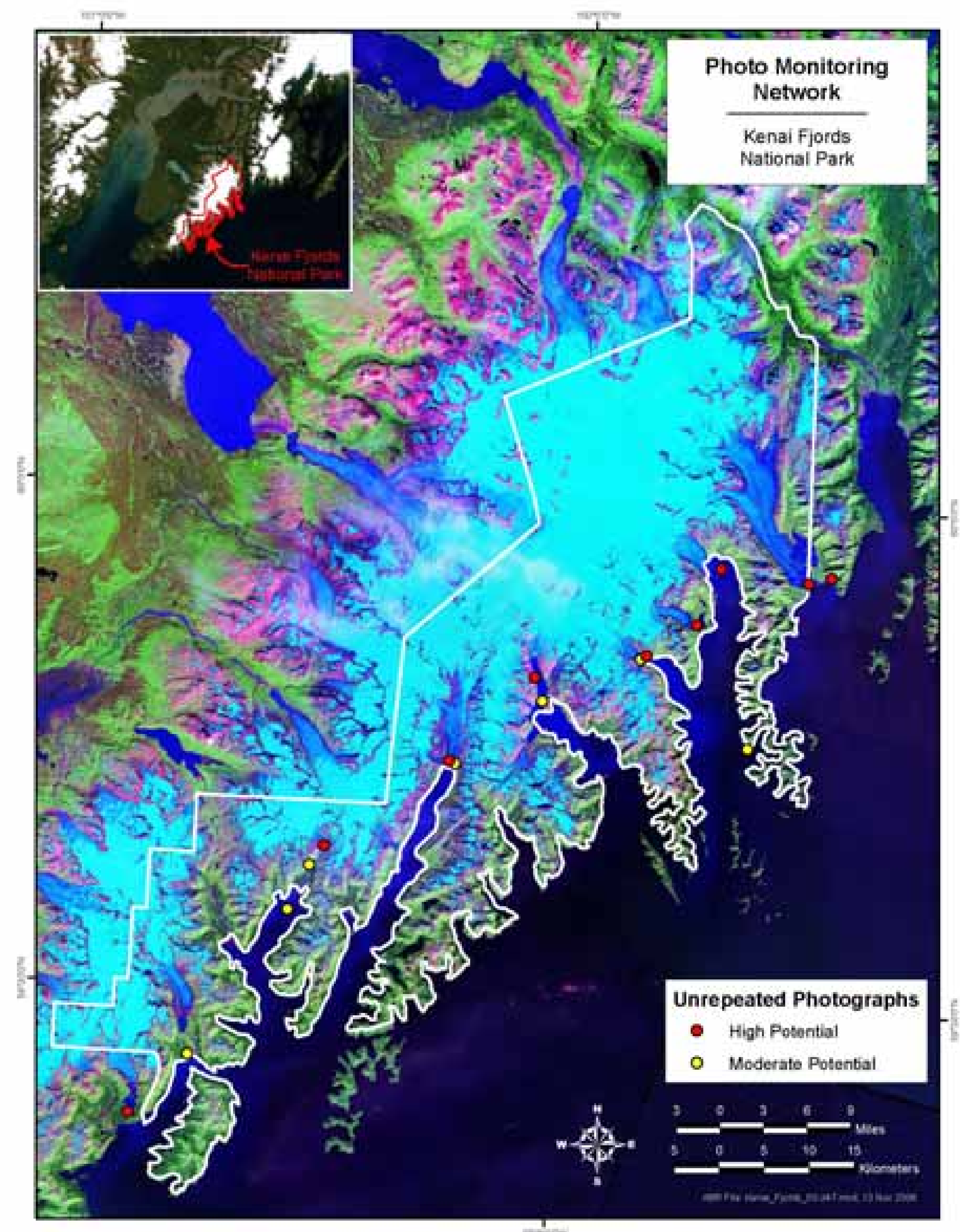

Figure 4. Photo-monitoring network developed for Kenai Fjords National Park. Location of unrepeated photos are estimated.

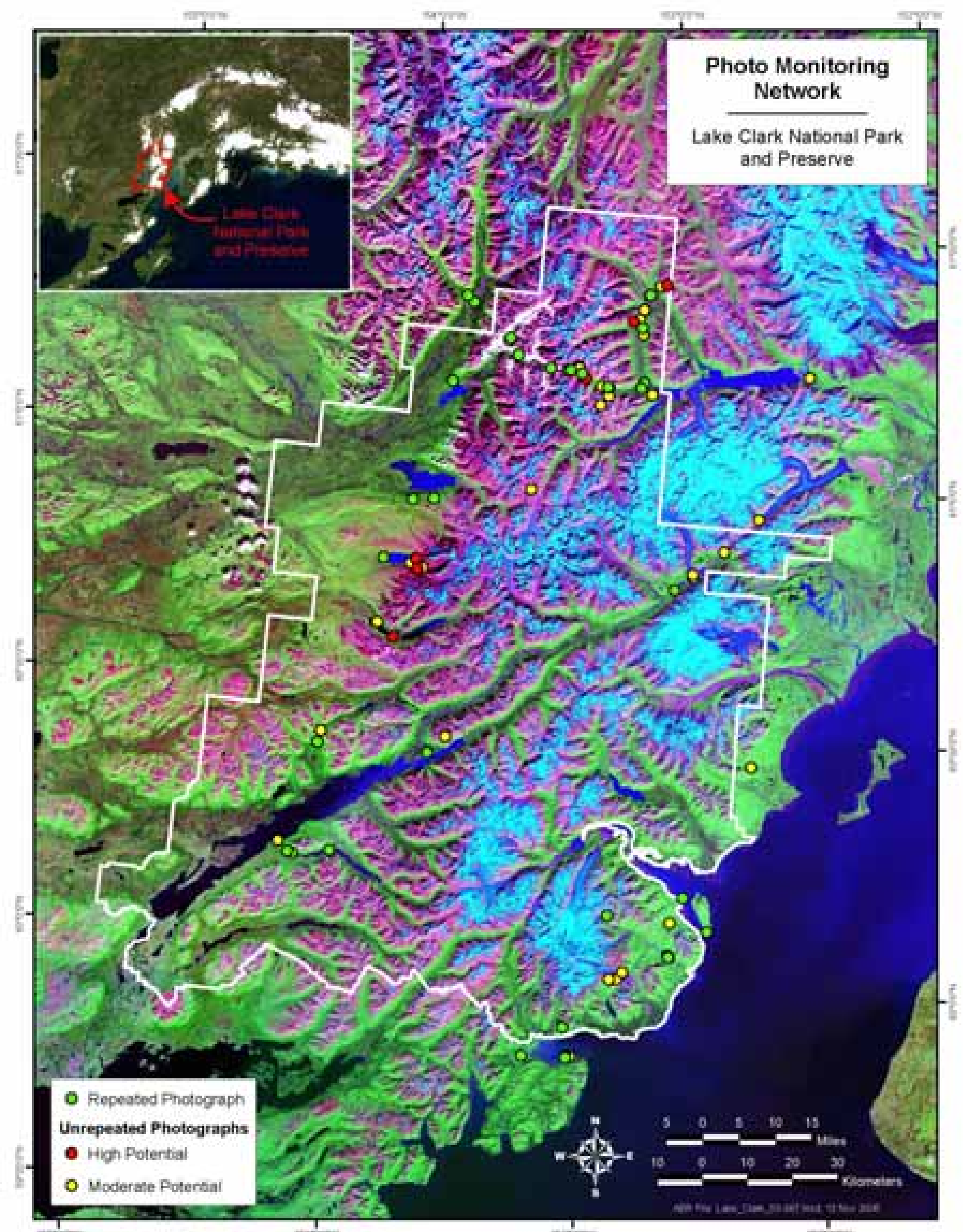

Figure 5. Photo-monitoring network developed for Lake Clark National Park and Preserve. Location of unrepeated photos are estimated.

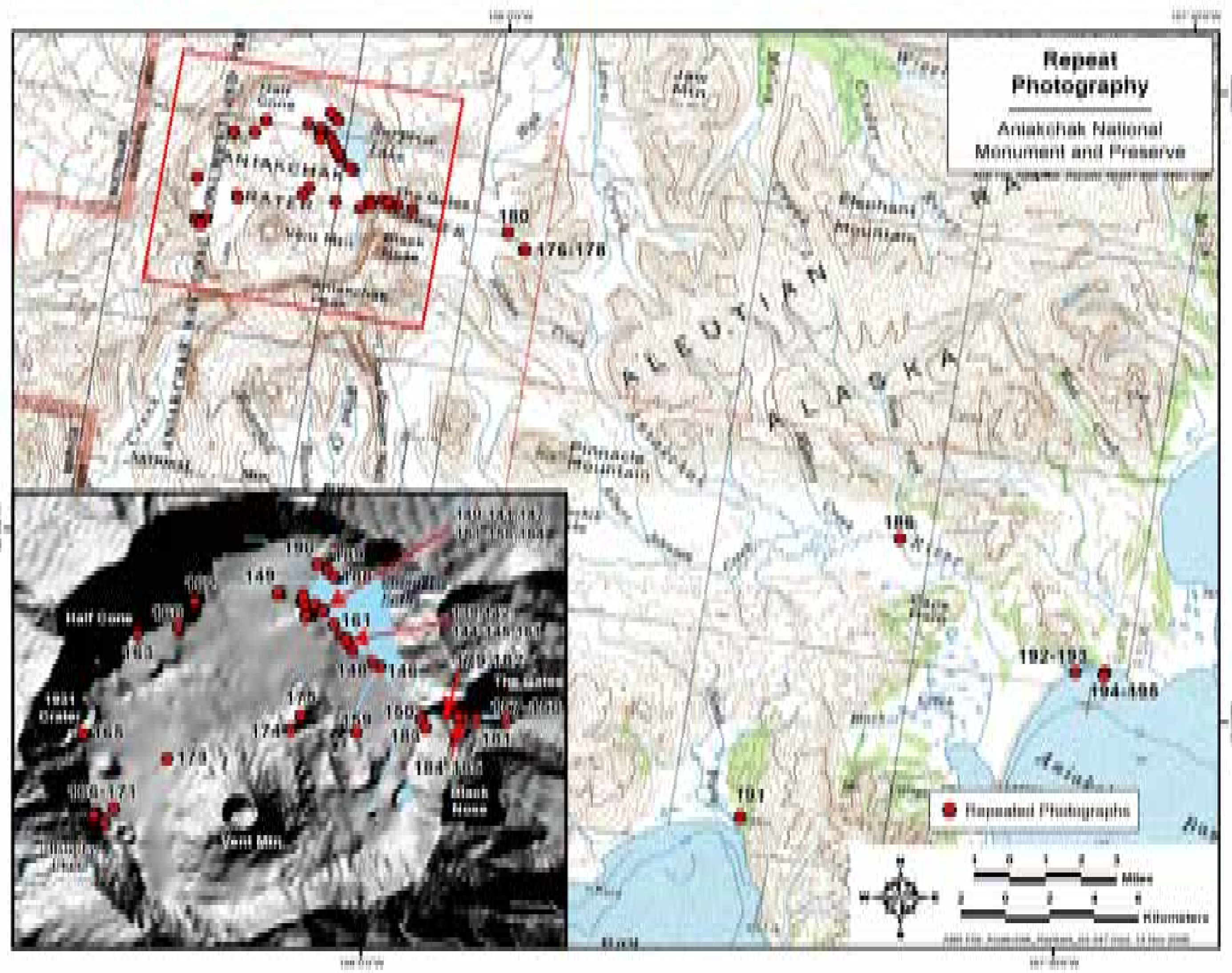

Figure 6. Location map and figure numbers of selected repeated photographs for Aniakchak National Monument and Preserve. Location of unrepeated photos are estimated.

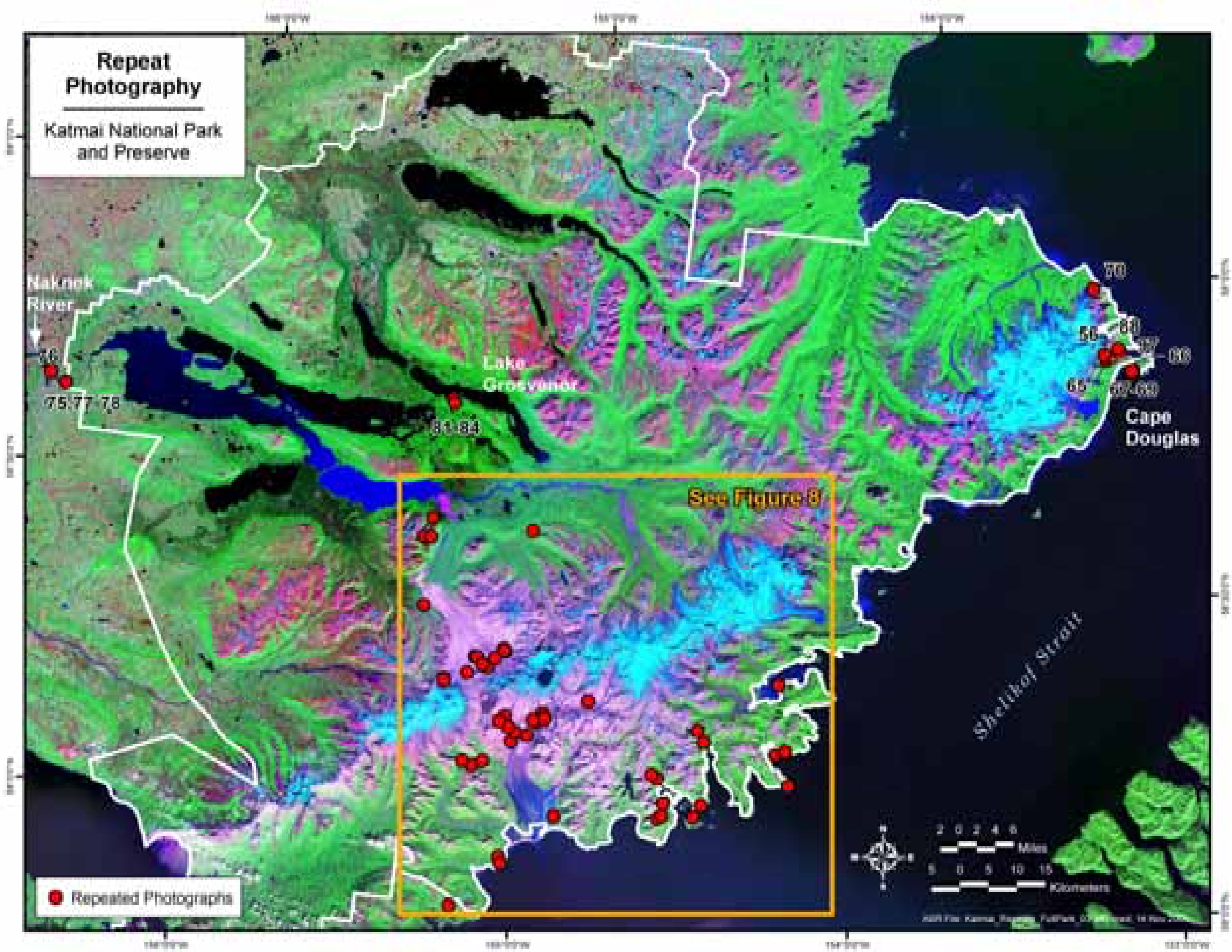

Figure 7. Location map and figure numbers of selected repeated photographs for Katmai National Park and Preserve.

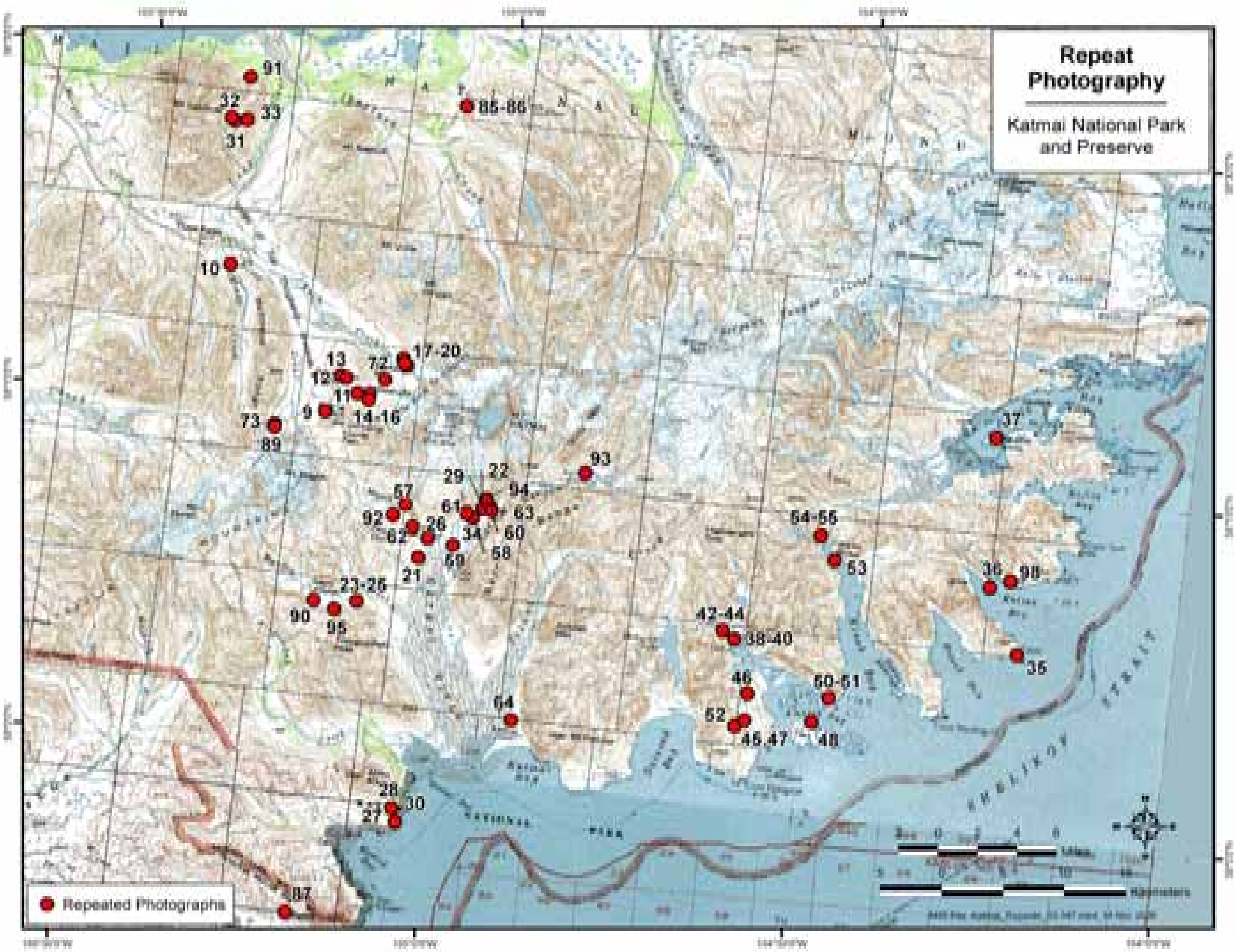

Figure 8. Location map and figure numbers of selected repeated photographs for southern coastal portions of Katmai National Park and Preserve.

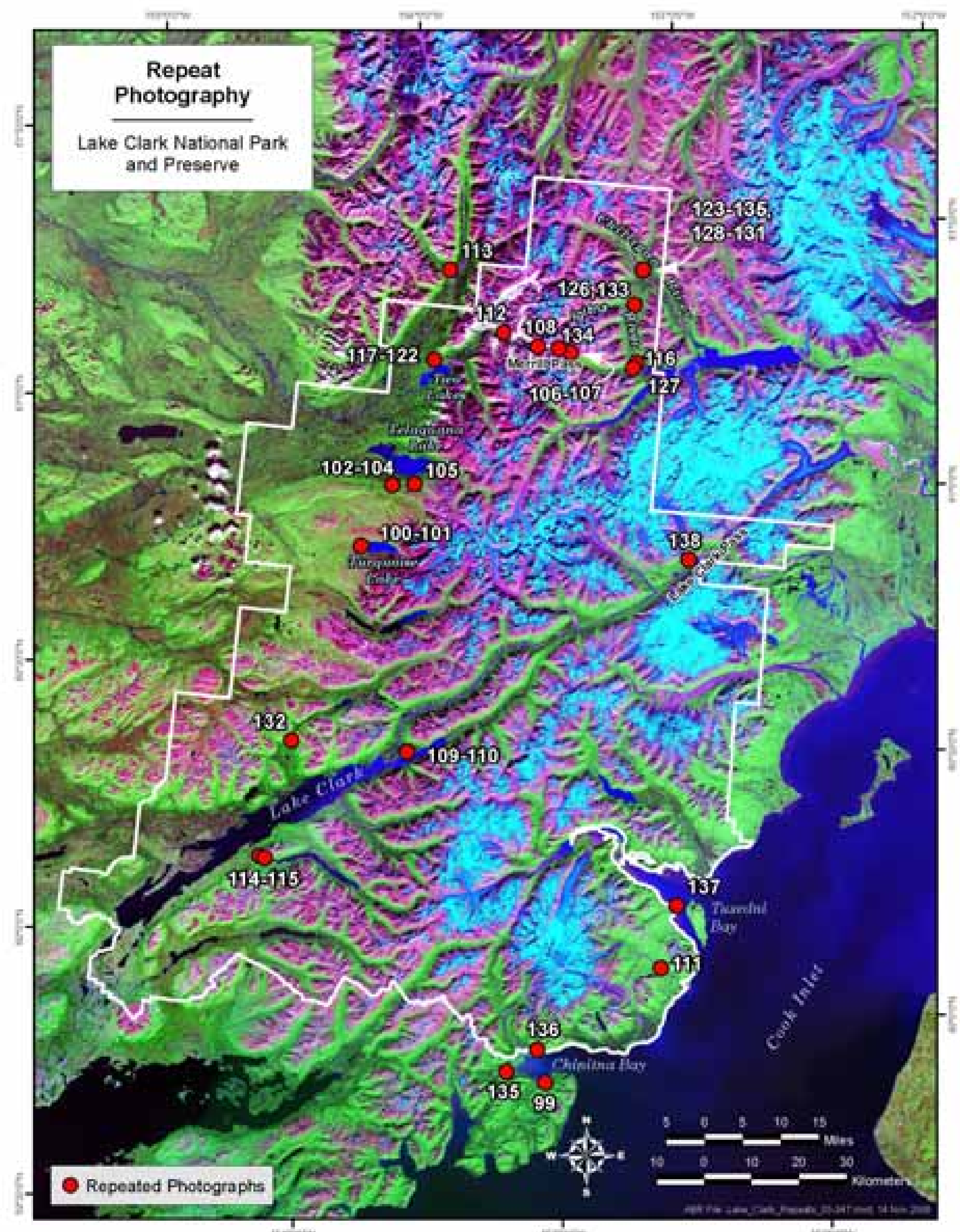

Figure 9. Location map and figure numbers of selected repeated photographs for Lake Clark National Park and Preserve.

Figure 10. Looking down the Valley of Ten Thousand Smokes from a historic campsite at the base of Mt. Cerberus in 1922 (W. Smith) and 2004 (G. Frost). Comparison illustrates that plant colonization of this young, inorganic surface has occurred at a very slow pace. The absence of stabilizing vegetation has led to extensive gully erosion across the valley floor. 1922 photo courtesy of USGS.

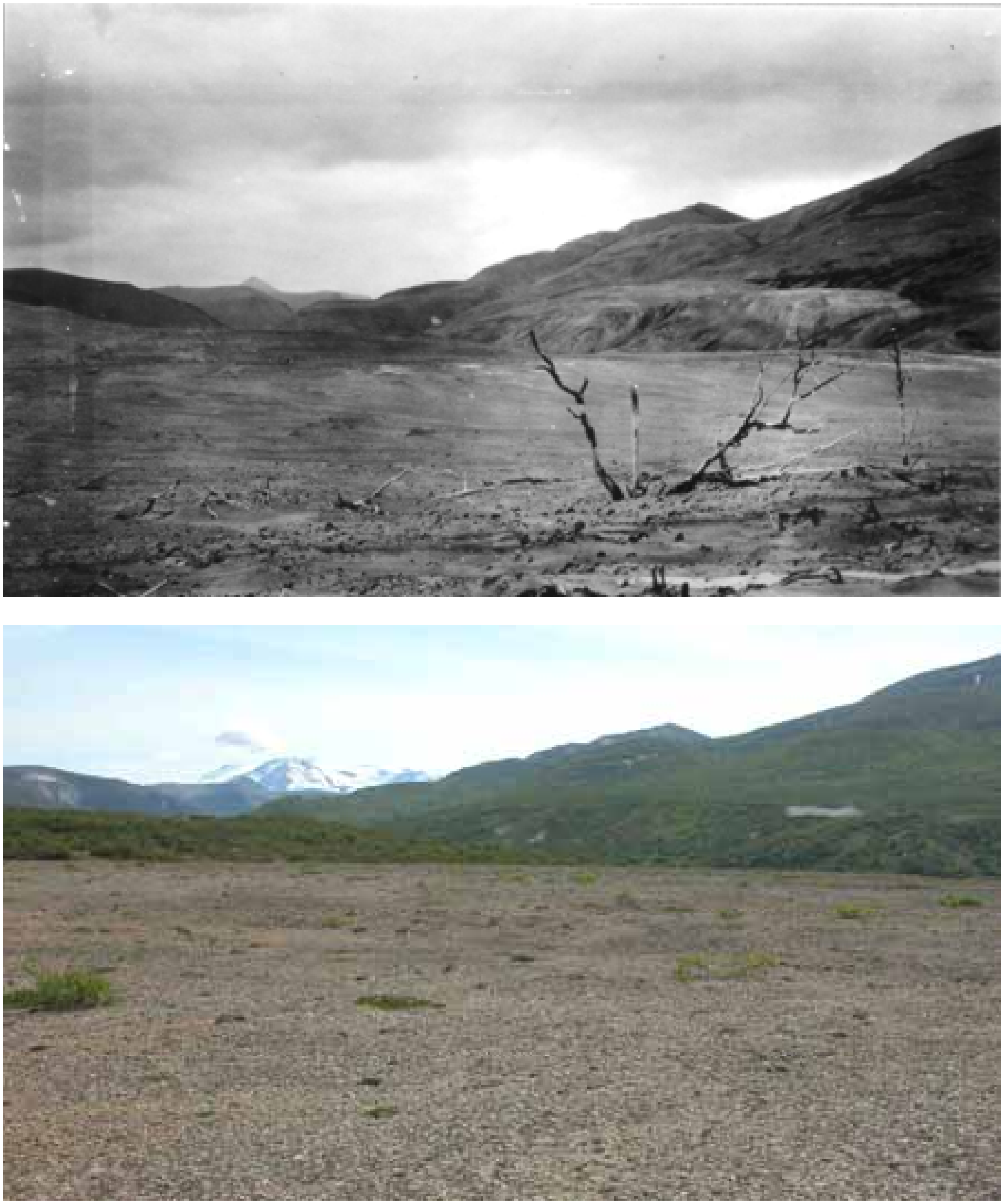

Figure 11. Looking up the Windy Creek drainage from the lower Valley of Ten Thousand Smokes near Three Forks in 1922 (W. Smith) and from approximately the same location in 2004 (G. Frost). The charred remains of a shrub in the 1922 foreground indicate that 1912 pyroclasts are very thin here, although it is likely that the buried 1912 organic horizon was burned. Primary succession on this young surface is occurring at a very slow pace. In contrast, secondary succession on background slopes affected by ashfall has occurred at a much faster pace. New foreground vegetation is composed primarily of willows. 1922 photo courtesy of USGS.

Figure 12. Falling Mountain (left), Mt. Cerberus (center), and the upper Valley of Ten Thousand Smokes seen just west of Novarupta in 1923 (C. Yori) and 2004 (G. Frost). The concentric gullies in the foreground are probably concussion fissures that formed during the latter stages of the eruption. Comparison reveals moderate erosion of this young, sparsely vegetated surface. New vegetation is primarily composed of willows. The large pumice boulder at center of the 1923 image has broken up.

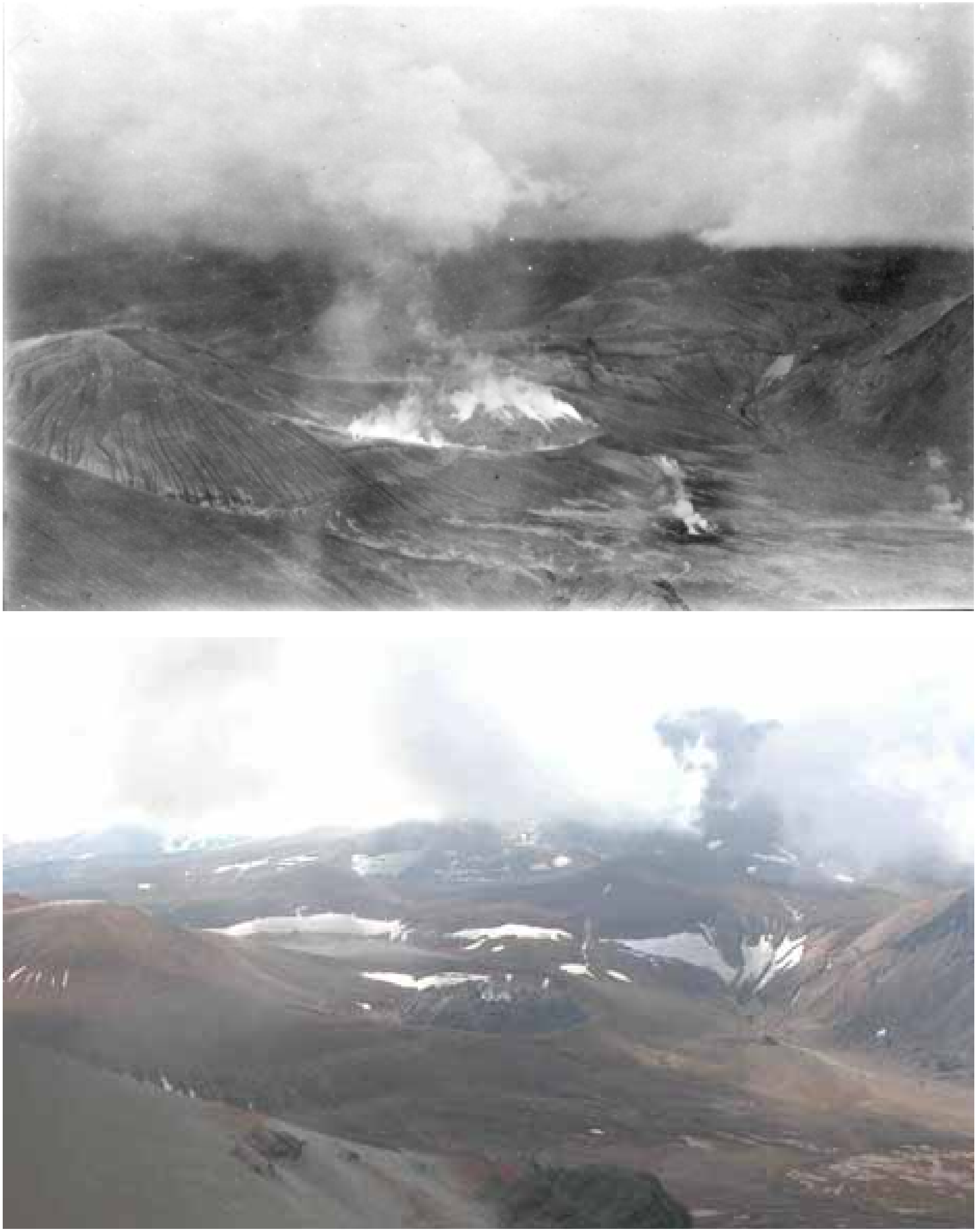

Figure 13. Novarupta area from summit of Baked Mountain in 1922 (W. Smith) and 2004 (G. Frost). Note the steaming fumaroles to the lower right of Novarupta. These fumaroles were active at least until the 1930s, but today provide favorable microsites for colonizing plants (see Figure 8). Elsewhere, primary succession is occurring at a very slow pace on the young volcanic surface. 1922 photo courtesy of USGS.

Figure 14. “The Turtle” seen from the upper slopes of Baked Mountain in 1922 (W. Smith) and 2004 (G. Frost). In general, the primary succession on the area’s young volcanic surface has occurred at a very slow pace. However, certain microsites are relatively favorable to plant colonists, such as the concussion fissures on The Turtle and the linear fumarole seen steaming at far right of the 1922 image. 1922 photo courtesy of USGS.

Figure 15. Novarupta seen from saddle between the River Lethe and Knife Creek drainages in 1918 (P. Hagelbarger) and 2004 (G. Frost). Although primary succession in the Valley of Ten Thousand Smokes is occurring very slowly, new vegetation composed chiefly of willows (*Salix barclayi*) and wood-rushes (*Luzula* spp.) has established at this site. 1918 photo courtesy National Geographic Society.

Figure 16. Strongly active in photographs as late as 1930, this extinct fumarole pit near Novarupta now supports one of the most conspicuous and diverse pockets of vegetation in the Valley of Ten Thousand Smokes. Vegetation is dominated by willows and forbs. Nitrogen-rich fumarolic gases such as ammonia that were recorded here by Griggs in 1930 have probably helped to ameliorate soil conditions at the site.

Figure 17. Photos taken near the termini of the second & third Knife Creek Glaciers in 1954 (V. Cahalane) and 2004 (G. Frost) provide comparative views of primary succession 42 and 92 years after the eruption of Novarupta. In both photos, vegetation is dominated by low feltleaf willow (*Salix alaxensis*). Many individual willows visible in the 1954 photograph were still present in 2004. New vegetation is particularly evident in the small gullies on the knoll at center. Continued gully erosion of pumice & ash deposits is evident in the foreground. The tephra-covered glacier in the background appears to have advanced slightly since 1954.

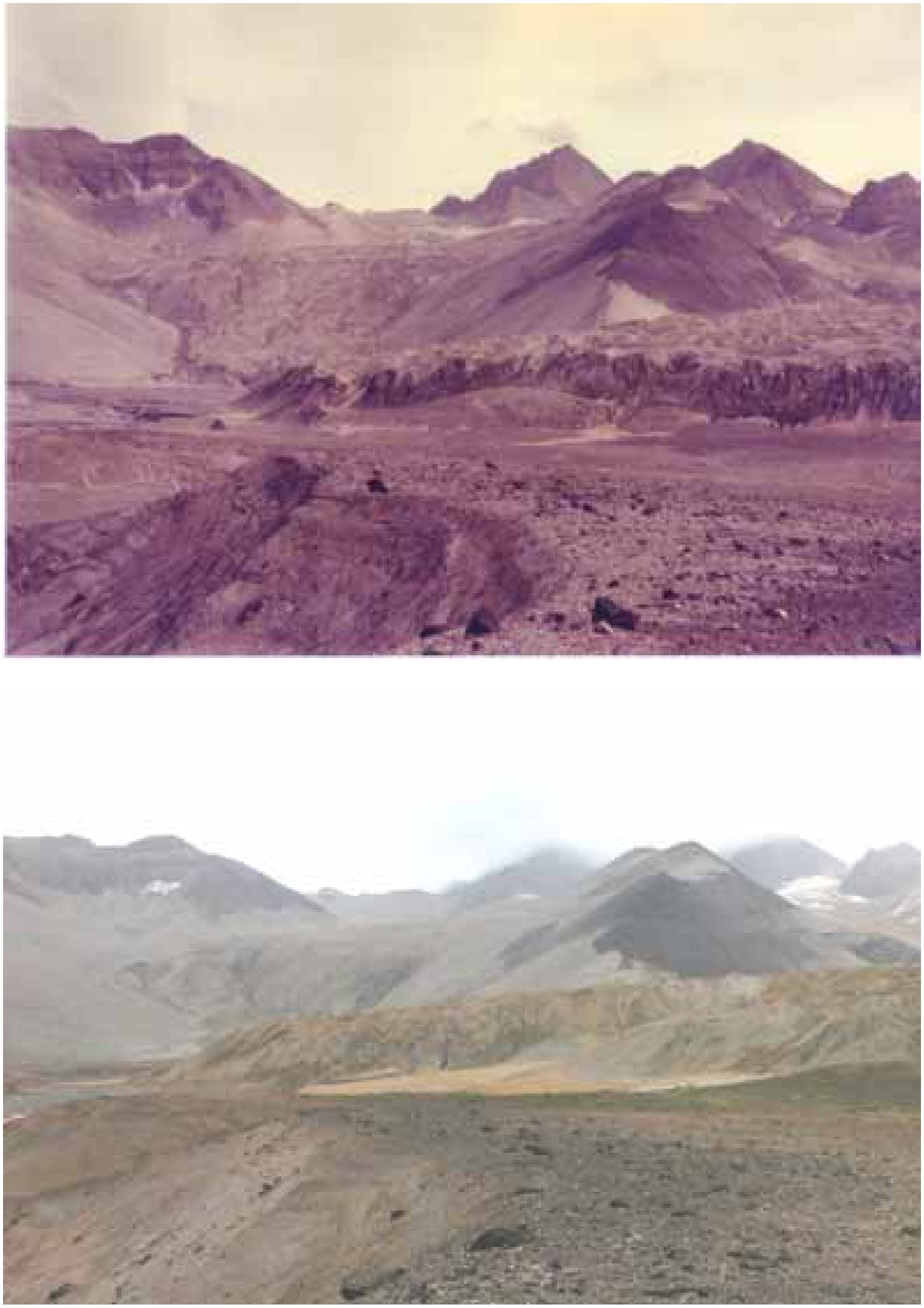

Figure 18. Panorama of Knife Creek Glaciers, seen from high ground between north and south forks of Knife Creek, in 1954 (V. Cahalane) and 2004 (G. Frost). Erosion of the slope in the foreground is evident, preventing exact duplication of the original vantage point. The ash-covered Knife Creek Glaciers have not changed much since 1954. Plant colonization of the young volcanic surface has occurred at a slow pace, but low willows have become more abundant.

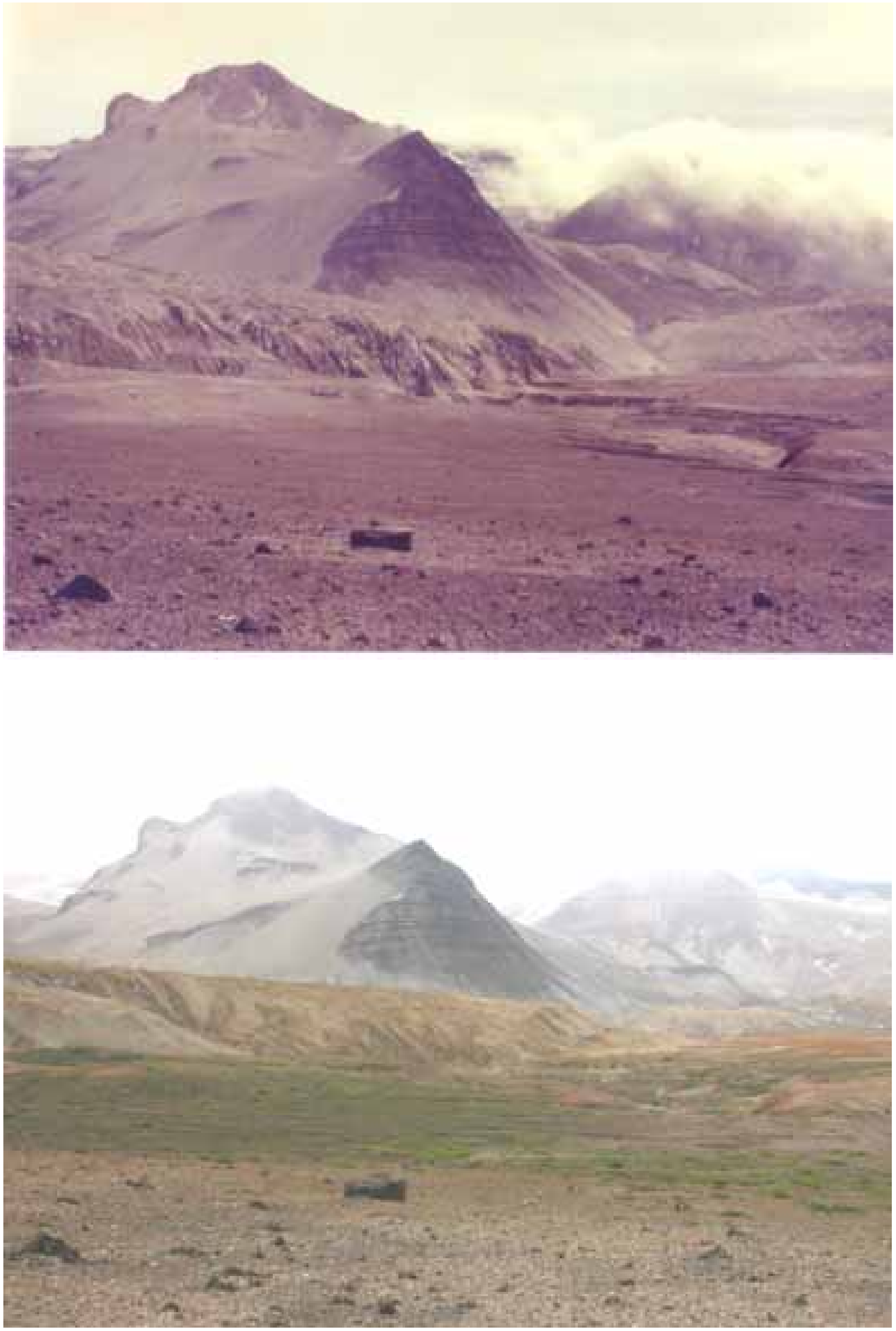

Figure 19. Continuation of panorama of Knife Creek Glaciers in 1954 (V. Cahalane) and 2004 (G. Frost). The ash-covered Knife Creek Glaciers have not changed much since 1954. However, low willow shrubs have become substantially more abundant in the middle ground.

Figure 20. Continuation of panorama of Knife Creek Glaciers in 1954 (V. Cahalane) and 2004 (G. Frost). The South Fork of Knife Creek (background right) has developed a slot canyon and the 1954 floodplain is barely recognizable. The ash-covered Knife Creek Glaciers have not changed much since 1954. However, low willow shrubs have become substantially more abundant in the foreground.

Figure 21. Unnamed creek northwest of confluence of Mageik Creek and Katmai River, looking east from base of Observation Mtn., in 1917 (D. Church) and 2004 (G. Frost). Used as a campsite by Griggs' expeditions, this sheltered creek bottom now supports willows, fireweed (*Chamerion angustifolium*), and bluejoint. The photo and expedition accounts suggest that the creek removed 1912 tephra deposits, likely permitting some vegetation lining the stream to survive. Surfaces in the immediate foreground and on the knoll at right have been stripped of both 1912 tephra and the pre-1912 organic soil horizon, while pre-1912 organics were still evident in vegetated areas in the foreground. 1917 photo courtesy National Geographic Society.

Figure 22. The south wall of Katmai Canyon seen from the southern slopes of Mt. Katmai in 1916 (D. Church) and 2004 (G. Frost). 1912 tephra did not persist on much of the steep canyon wall, while ash and pumice is prevalent on the relatively gentle terrain in the foreground. Tall alder scrub has recovered on many sites in the background. The small tephra-covered glacier at upper left appears little changed. 1916 photo courtesy National Geographic Society.

Figure 23. Uplands south of lower Martin Creek in 1917 (unknown) and 2005 (M. Jorgenson) at an elevation of 200 m. Ashfall here was light compared to areas southeast of Novarupta and vegetation recovery is at an advanced stage. Today, tall shrub thickets are intermixed with dwarf scrub and herbaceous meadows, although the snags in the 1917 photo suggest that the area supported trees before 1912. The pond at middle right appears unchanged. 1917 photo courtesy National Geographic Society.

Figure 24. Looking down Martin Creek valley from uplands to south at an elevation of 200 m in 1917 (unknown) and 2005 (M. Jorgenson). Ashfall here was light compared to areas southeast of Novarupta and vegetation recovery is at an advanced stage. The Barrier Range and lower Katmai River valley (background) were more severely disturbed by the 1912 eruption and retain more bare ground. 1917 photo courtesy National Geographic Society.

Figure 25. Looking up Martin Creek valley from uplands to south at an elevation of 200 m in 1917 (unknown) and 2005 (M. Jorgenson). Ashfall here was light compared to areas southeast of Novarupta, although it was severe enough to kill the foreground vegetation. Today, vegetation recovery is at an advanced stage. 1917 photo courtesy National Geographic Society.

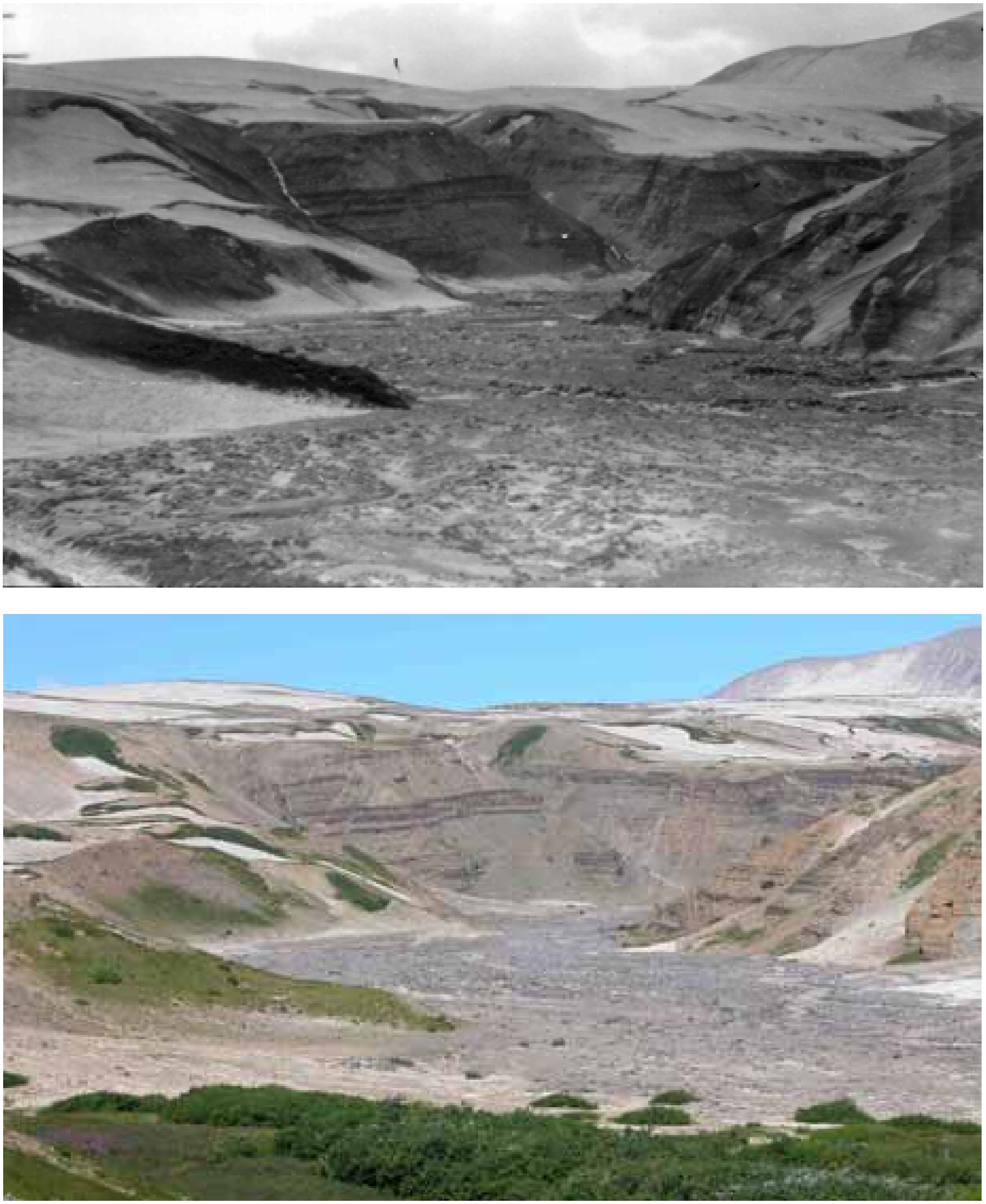

Figure 26. Photos taken in 1929 (B. Hubbard) and 2004 (G. Frost) illustrate plant succession along the floodplain of lower Mageik Creek. 2004 foreground vegetation is dominated by pioneering feltleaf willow, fireweed, and bluejoint. Tephra-covered slopes in the background now support scattered low willows, forbs, sedges, and grasses, although many of these areas are still barren 92 years after the eruption of Novarupta. 1929 photo courtesy Santa Clara University.

Figure 27. Small wetland below Atmo Mountain seen in 1917 (J. Sayre) and 2005 (M. Jorgenson); the 1917 photo was not taken level. Photo comparison reveals that a typical palustrine successional sequence has occurred at this site. By 2005, early-successional, aquatic yellow pondlily (*Nuphar polysepalum)* has colonized the remaining open water, while cover of later-successional species including buckbean (*Menyanthes trifoliate*), purple marshlocks (*Comarum palustre*), and sedges (*Carex* & *Eriophorum* sp.) has increased. Although this site is only 20 miles away from Mt. Katmai, disturbance associated with the 1912 eruption appears to have been minimal. 1917 photo courtesy National Geographic Society.

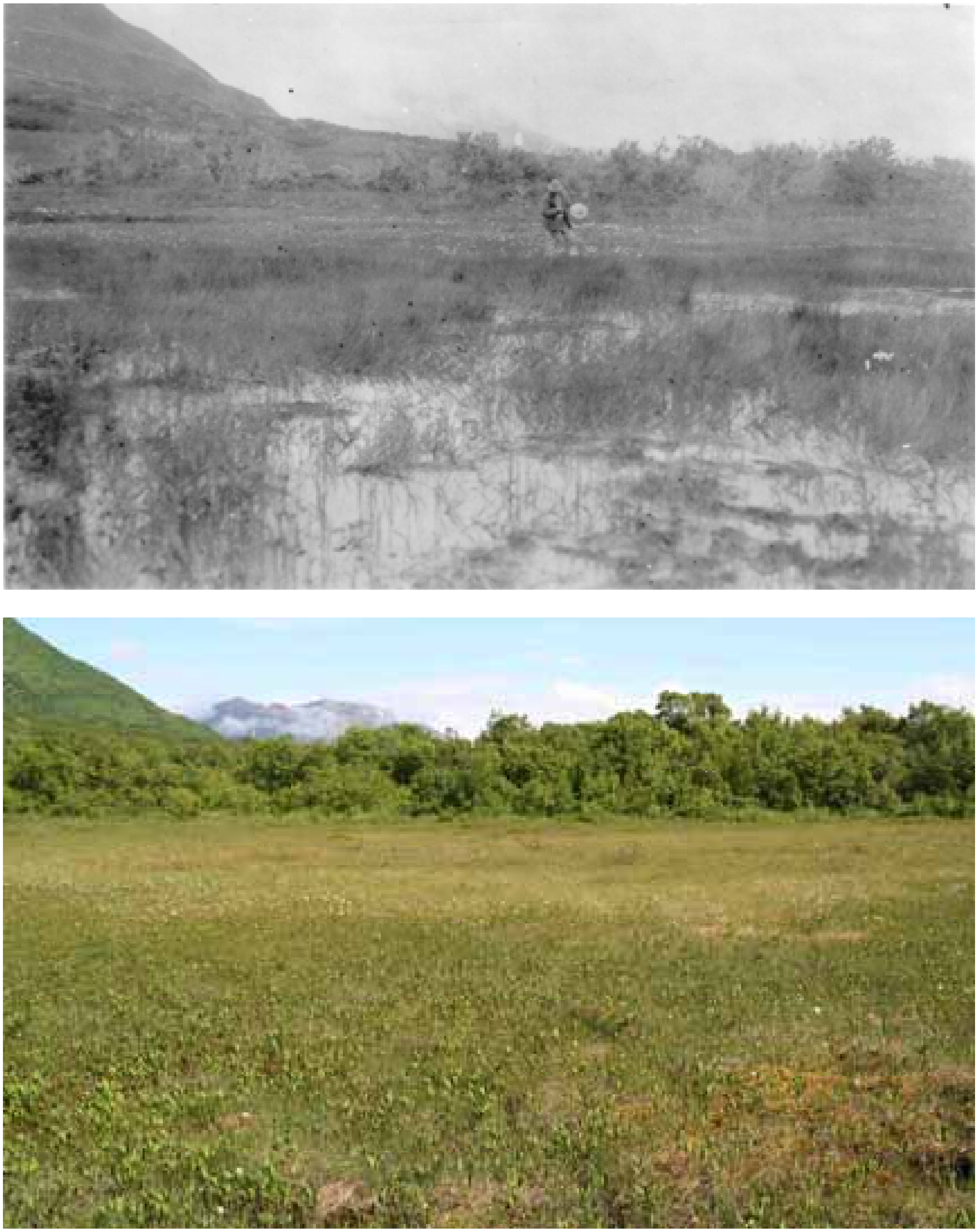

Figure 28. Small wetland below Atmo Mountain seen in 1917 (J. Sayre) and 2005 (M. Jorgenson). A typical palustrine successional sequence is apparent at this site, as live vegetation and accumulating peat have replaced open water. Later-successional species including buckbean, purple marshlocks, and sedges are dominant in the wetland. Deciduous trees and tall shrubs appear to be taller and more abundant in the background. Disturbance associated with the 1912 eruption appears to have been minimal here. 1917 photo courtesy National Geographic Society.

Figure 29. Looking down the Katmai River at exit of Katmai Canyon, from southern base of Mt. Katmai, in 1917 (R. Griggs) and 2004 (G. Frost). New vegetation is most abundant where 1912 tephra has been stripped. Tall alder shrubs are recovering on steep Barrier Range slopes (background), while scattered graminoids, forbs, and dwarf shrubs are prevalent in the foreground. Continued channel migration on the braided river floodplain has prevented vegetation from establishing there. 1917 photo courtesy National Geographic Society.

Figure 30. Looking inland north of Kashvik Bay in 1917 (R. Griggs) and 2005 (M. Jorgenson). Griggs' 1917 image shows balsam poplar (*Populus balsamifera*) snags here, although it is not clear if the trees were killed as a result of 1912 volcanic disturbance. Almost 90 years of succession has produced a stand similar to what existed prior to Griggs' visit, with stunted balsam poplars mixed with tall alder and willow shrubs. Tall shrubs appear to be more abundant along the low ridge in background. 1917 photo courtesy National Geographic Society.

Figure 31. Eastern slopes of Mt. Katolinat at an elevation of 855 m, looking toward the Valley of Ten Thousand Smokes, in 1918 (J. Sayre) and 2005 (M. Jorgenson). Sayre's 1918 image reveals that 1912 ashfall persisted at this site for at least six years, although ash depth was shallow relative to areas southeast of Novarupta. Recovery of alpine tundra is apparent, with 2005 foreground vegetation dominated by arctic willow (*Salix arctica)*, crowberry (*Empetrum nigrum)*, and blackish oxytrope (*Oxytropis nigrescens)*. 1918 photo courtesy National Geographic Society.

Figure 32. Looking towards Mt. La Gorce from the eastern slopes of Mt. Katolinat at 823 m elevation in 1918 (J. Sayre) and 2005 (M. Jorgenson). Sayre's 1918 image reveals that 1912 ashfall persisted at this site for at least six years, although ash depth was shallow relative to areas southeast of Novarupta. Note the solifluction lobes in the 2005 image. Although it is difficult to assess changes in the solifluction features at this site, the recovery of alpine tundra is apparent. 1918 photo courtesy National Geographic Society.

Figure 33. Overlooking Ukak River valley and the Valley of Ten Thousand Smokes from an elevation of 870 m on the eastern slopes of Mt. Katolinat in 1918 (J. Sayre) and 2005 (M. Jorgenson). The dramatic recovery of vegetation in the Ukak River valley contrasts sharply with the barren Valley of Ten Thousand Smokes (right background). Channel migration has kept most of the Ukak River floodplain barren. 1918 photo courtesy National Geographic Society.

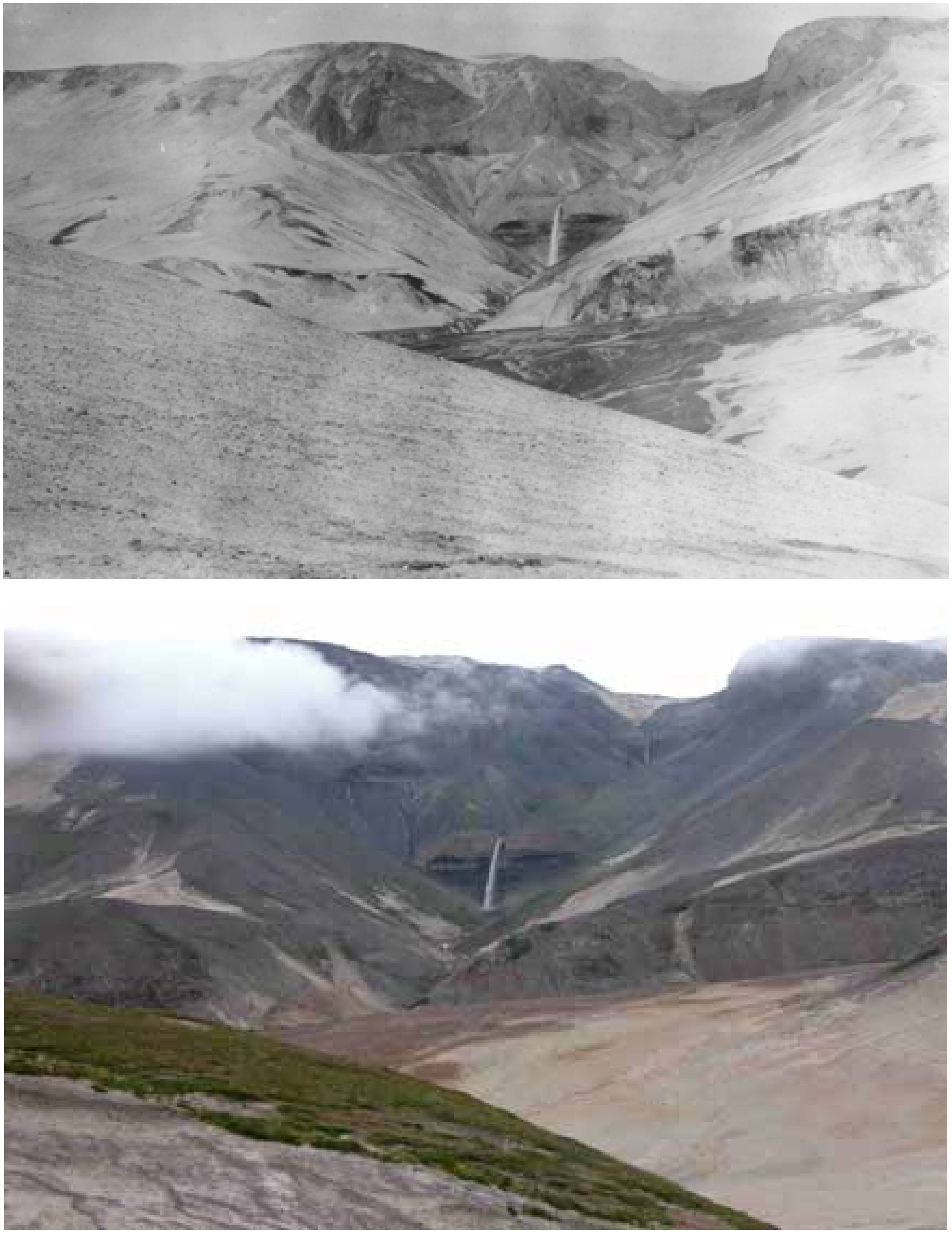

Figure 34. David's Falls and the southern slopes of Mt. Katmai, seen from knob near the outlet of Katmai Canyon, in 1919 (E. Kolb) and 2004 (G. Frost). Vegetation recovery has advanced appreciably only in areas where 1912 tephra deposits have been stripped, such as the steep slopes of Mt. Katmai and the exposed slope in the foreground. The two waterfalls appear unchanged. 1919 photo courtesy National Geographic Society.

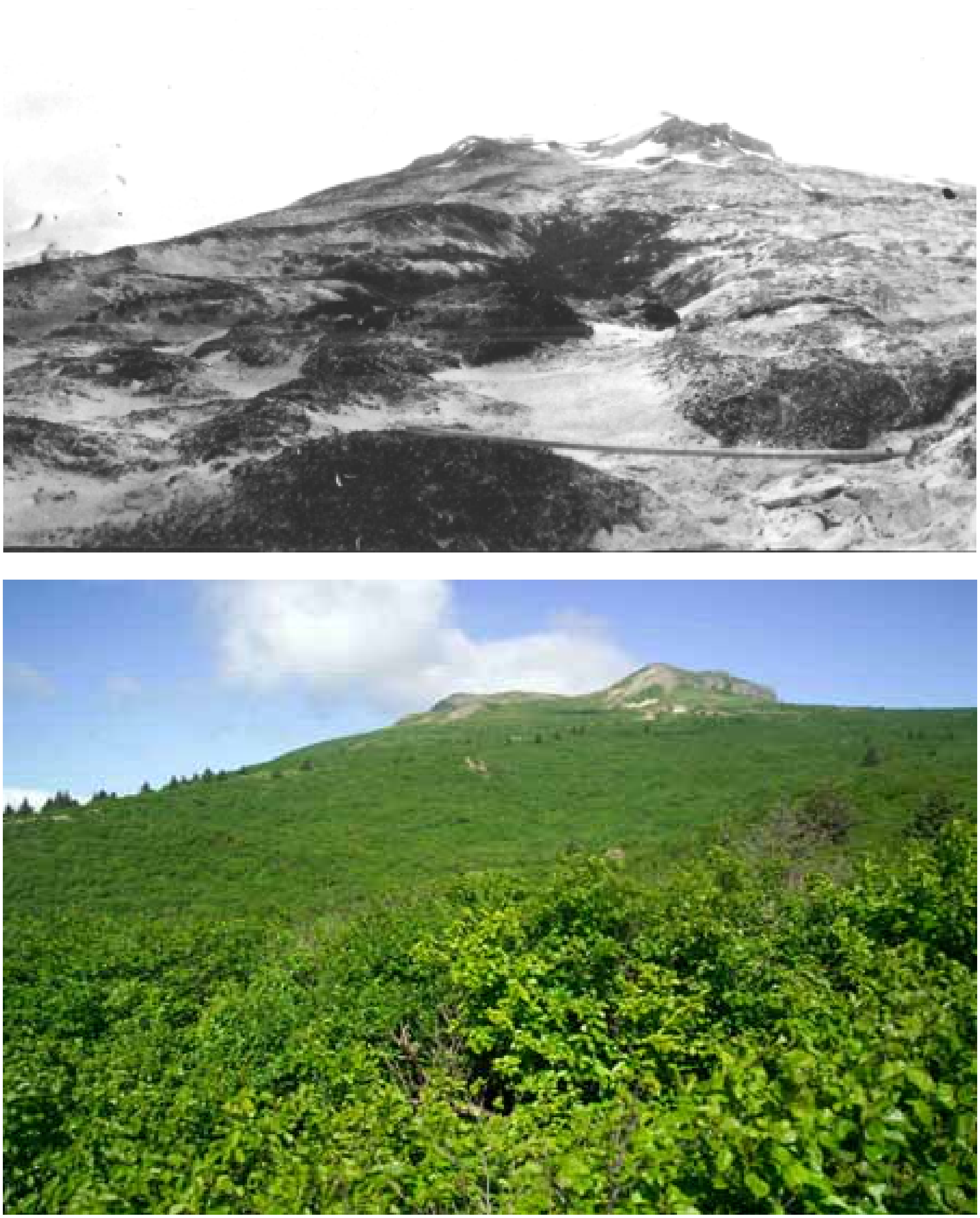

Figure 35. Coastal uplands west of Cape Kuliak in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). The ash-choked 1919 landscape now supports rank vegetation. Very little of the pre-1912 vegetation appears to have recovered by 1919, indicating that the vegetation at this site is composed of newly established plants rather than holdovers. However, the present alder-dominated community is probably very similar to what existed here before the 1912 eruption. 1919 photo courtesy National Geographic Society.

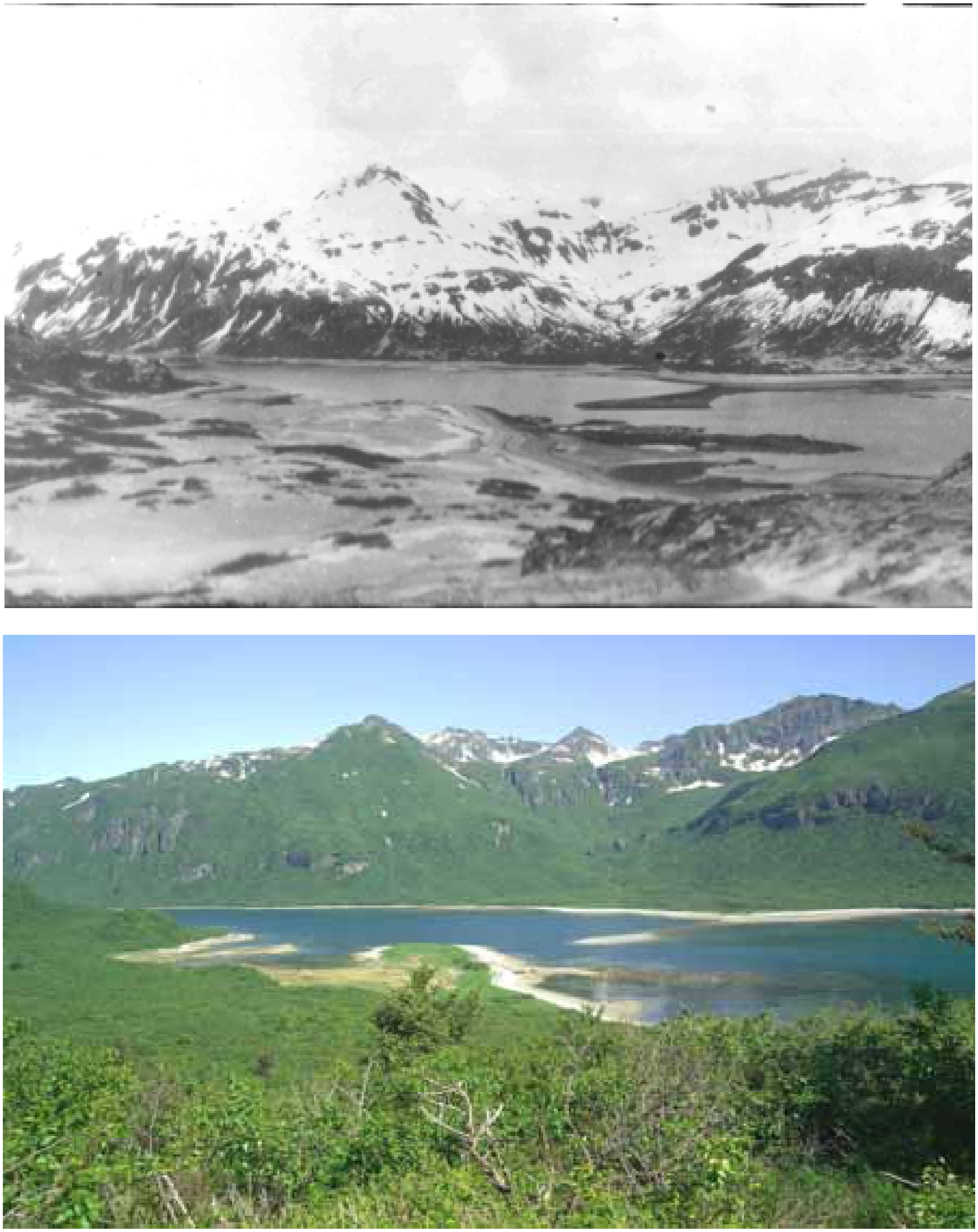

Figure 36. Looking northeast across north arm of Kuliak Bay in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). Scattered patches of alder that survived severe 1912 ashfall are evident on foreground slopes in the original image. Alders have since recovered dramatically. Differences in coastal features probably only reflect differing tidal levels at the times of photography. 1919 photo courtesy National Geographic Society.

Figure 37. Looking northwest across Kukak Bay from Aguchik Island in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). The recovery of vegetation at this site following severe 1912 ashfall is dramatically illustrated by the development of a Sitka spruce forest (*Picea sitchensis*). 1919 photo courtesy National Geographic Society.

Figure 38. Looking northwest from the head of Geographic Harbor in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). The 2005 vantage point was adjusted slightly due to dense vegetation at the original vantage point. The 1919 photo reveals that many alders survived 1912 ashfall on steep slopes where thick tephra deposits did not persist. Virtually all surfaces are vegetated by a mosaic of tall alder thickets and scattered herbaceous openings. 1919 photo courtesy National Geographic Society.

Figure 39. Looking south from the head of Geographic Harbor in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). Virtually all surfaces are now covered by dense tall alder thickets with scattered herbaceous openings, although a few thick, unconsolidated tephra deposits on background slopes remain entirely barren. 1919 photo courtesy National Geographic Society.

Figure 40. Looking east across the head of Geographic Harbor in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). Virtually all surfaces are now covered by dense tall alder thickets. A semihalophytic wet meadow now occupies the small delta built up by the creek at left. 1919 photo courtesy National Geographic Society.

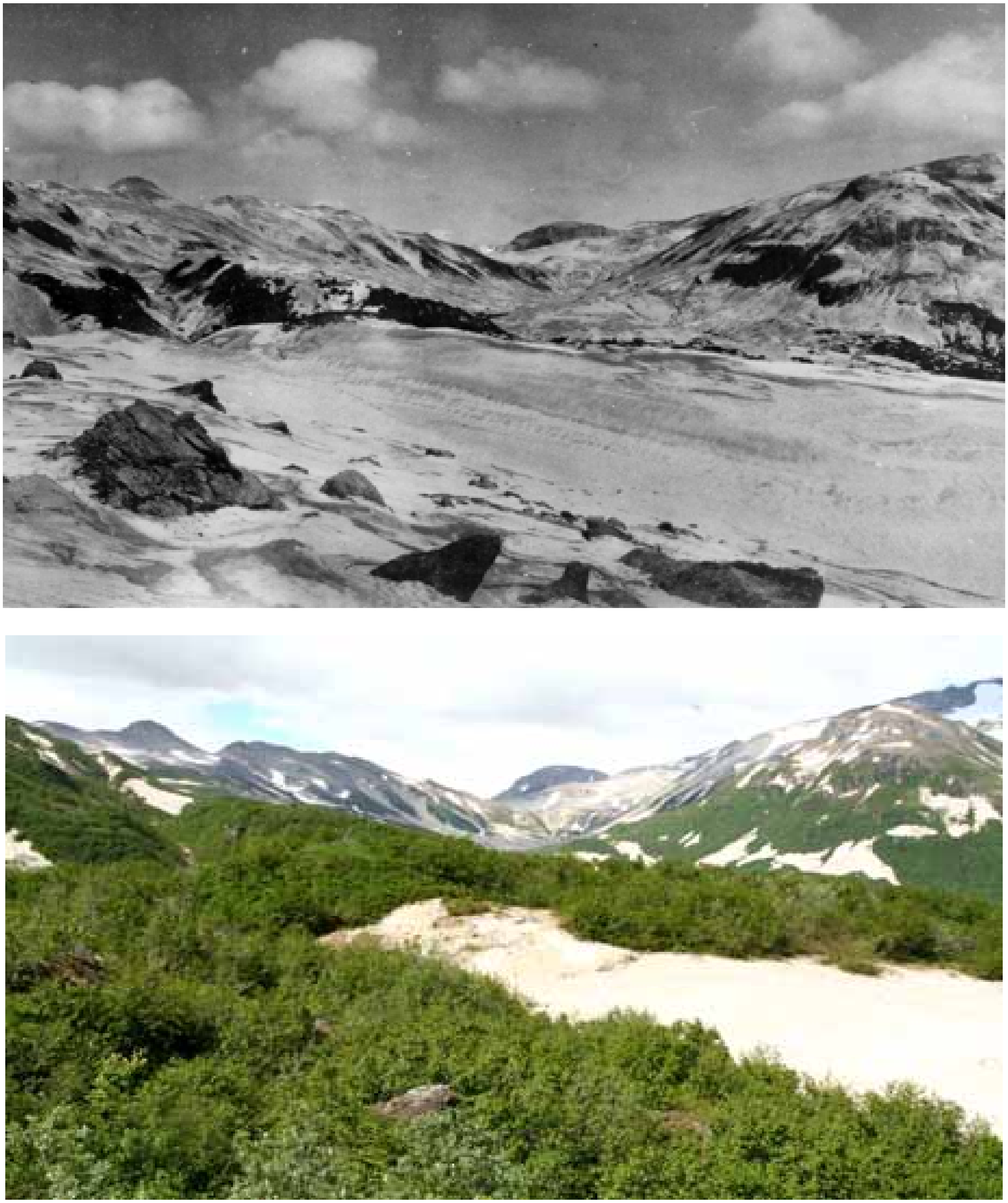

Figure 41. Mountains north of Geographic Harbor seen from an elevation of 330 m in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). Twenty miles from Novarupta and directly downwind of it at the time of the 1912 eruption, this site experienced some of the most severe ashfall recorded in the area. Initially alders survived on steep slopes (background), while gentler slopes (foreground) retained tephra and were much slower to recover. Unlike most other areas, barren tephra remains widespread here. 1919 photo courtesy National Geographic Society.

Figure 42. Mountains west of Geographic Harbor seen from an elevation of 330 m in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). Twenty miles from Novarupta and directly downwind of it at the time of the 1912 eruption, this site experienced some of the most severe ashfall recorded in the area. The 1919 image indicates very little live vegetation on nearby slopes. Although vegetation recovery is apparent, alder shrubs are widely spaced and barren tephra remains widespread here. 1919 photo courtesy National Geographic Society.

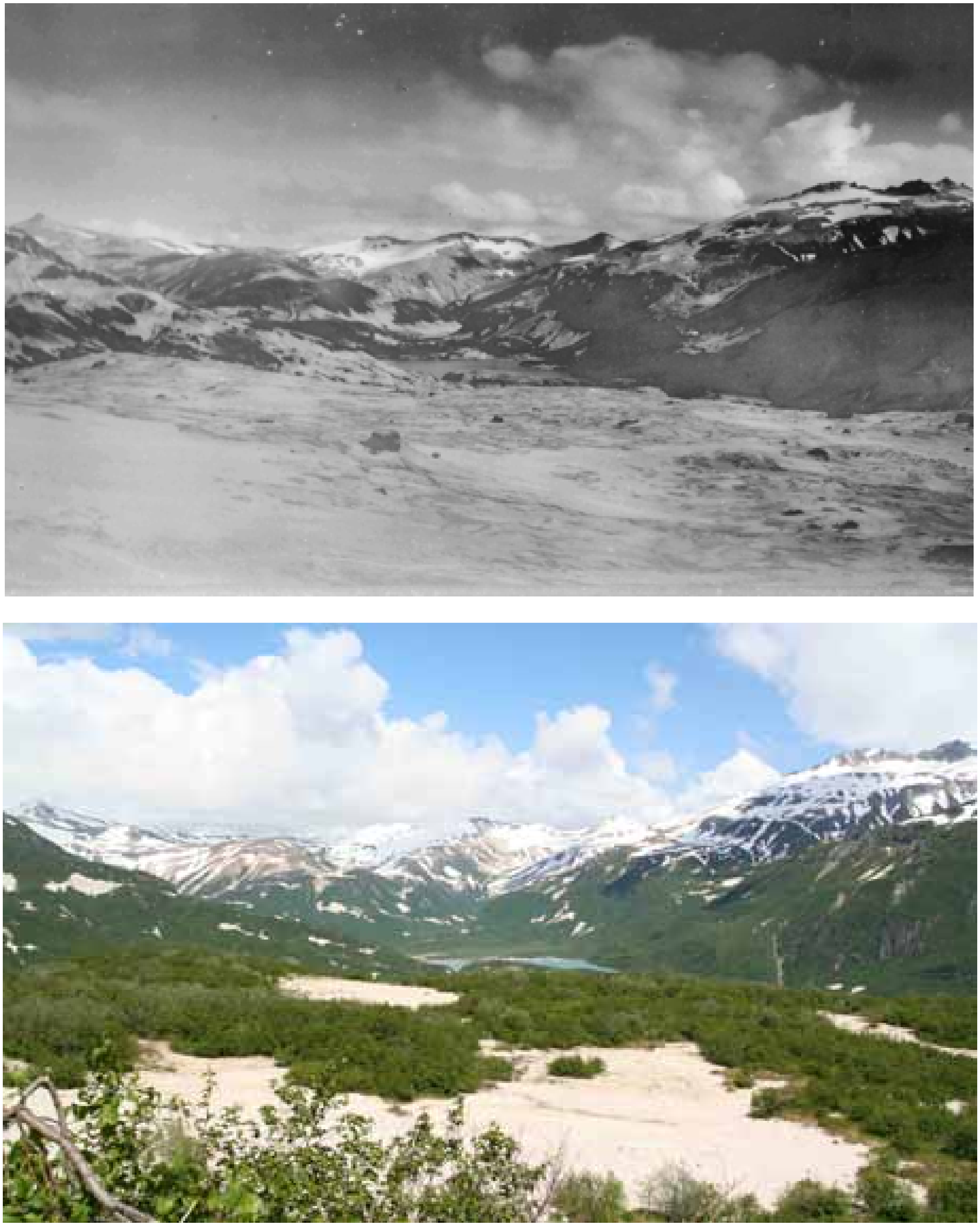

Figure 43. Mountains north of Geographic Harbor seen from an elevation of 330 m in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). The 1919 image indicates that alder survived only on steep background slopes. Barren tephra remains widespread on gentle foreground slopes. 1919 photo courtesy National Geographic Society.

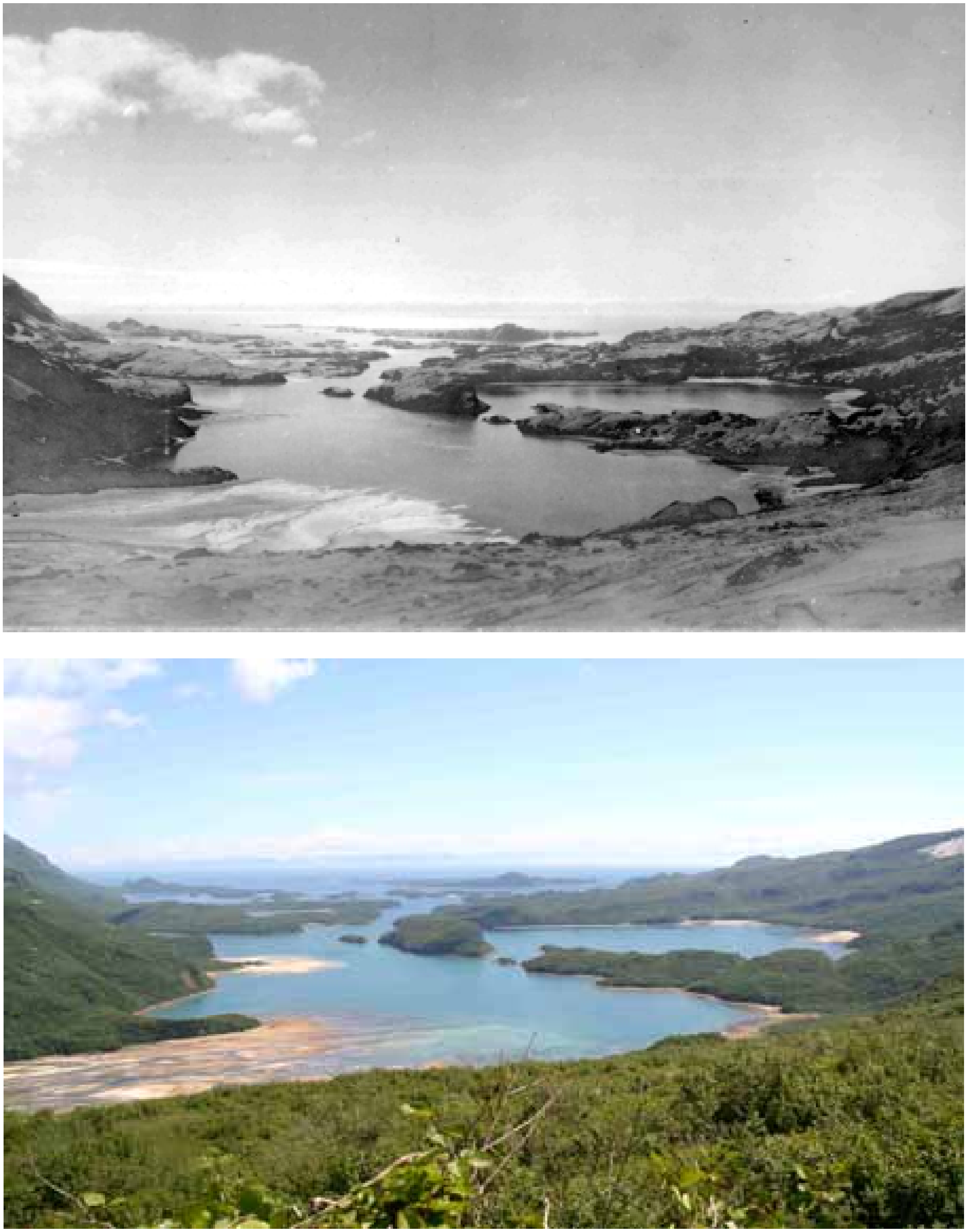

Figure 44. Geographic Harbor seen from an elevation of 330 m in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). Twenty miles from Novarupta and directly downwind of it at the time of the 1912 eruption, this site experienced some of the most severe ashfall recorded in the area. The recovery of alder in these coastal mountains is dramatically illustrated here. 1919 photo courtesy National Geographic Society.

Figure 45. Amalik Bay and Geographic Harbor, seen from uplands to southwest, in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). Alder recovery is widespread on the mountain slopes. Hagelbarger's 1919 panoramas reveal that patches of alder survived the 1912 ashfall on slopes where ash did not persist. 1919 photo courtesy National Geographic Society.

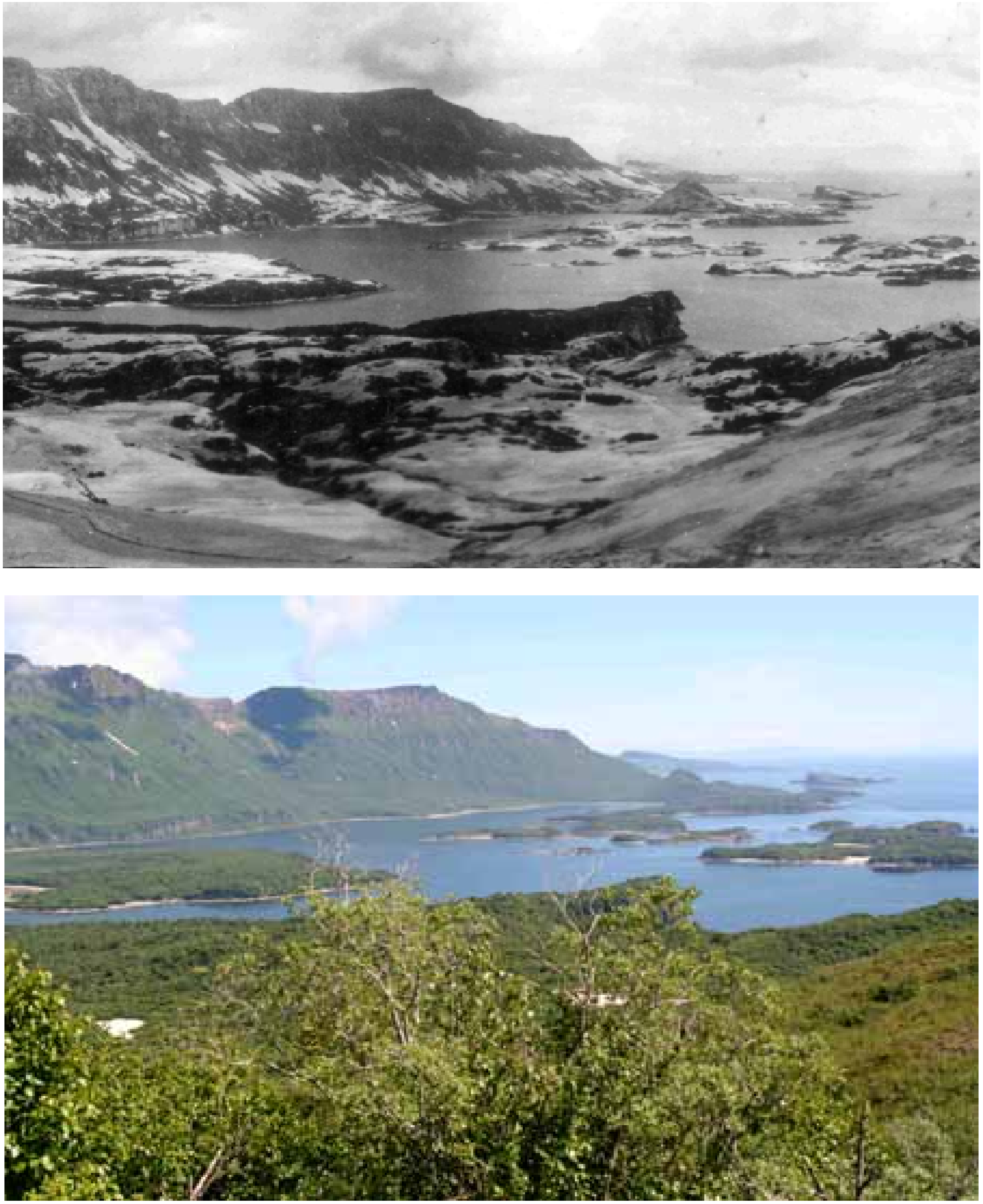

Figure 46. Amalik Bay, seen from uplands to southwest at an elevation of 278 m, in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). Recovery of tall shrub vegetation is widespread on the mountain slopes and islands. Hagelbarger's 1919 panoramas reveal that patches of alder survived 1912 ashfall on slopes where thick deposits did not persist. 1919 photo courtesy National Geographic Society.

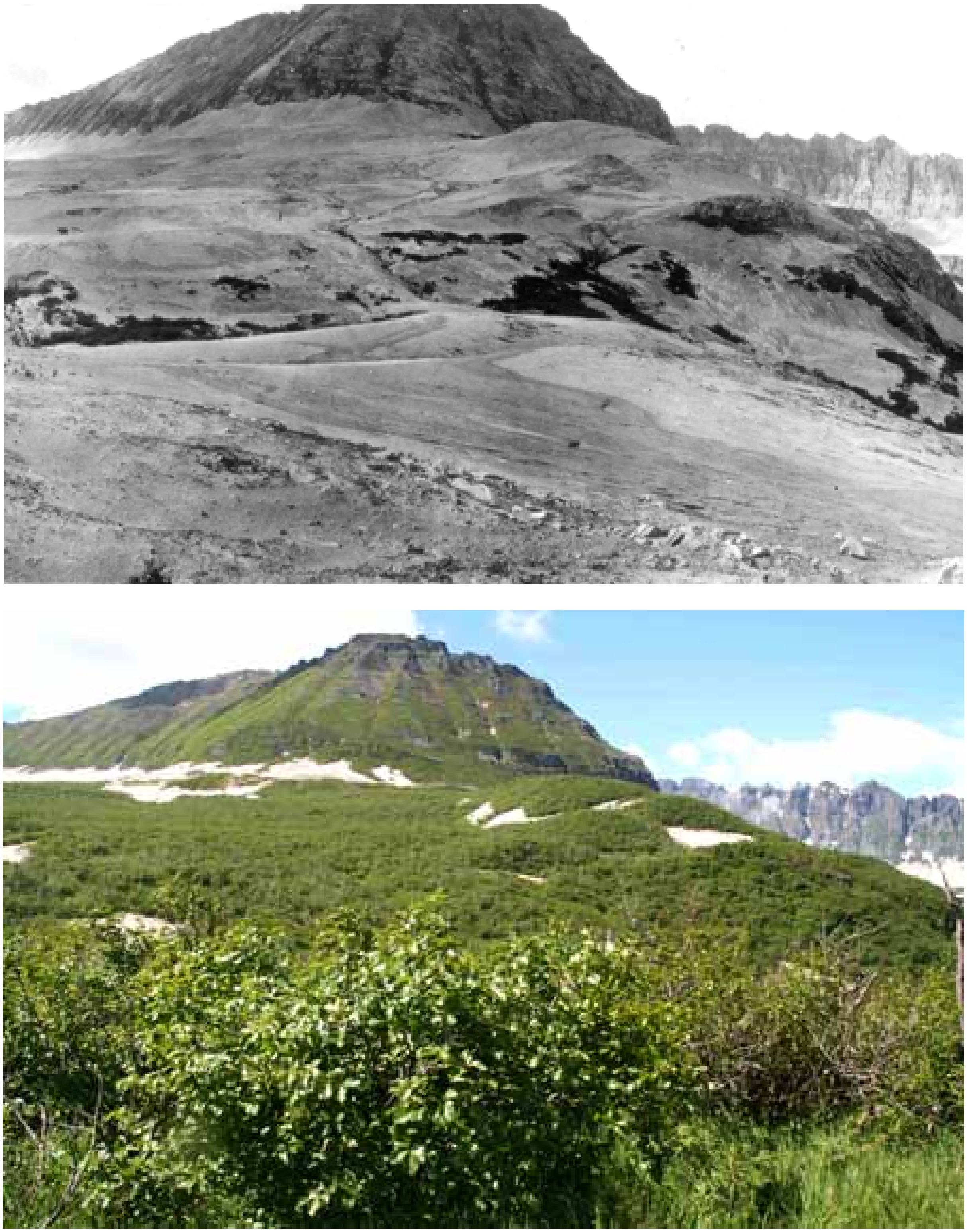

Figure 47. Coastal mountains west of Amalik Bay, seen from an elevation of 278 m, in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). Recovery of tall shrub vegetation is widespread on the mountain slopes. Thick colluvial accumulations of tephra on runout areas below steep slopes remain barren. 1919 photo courtesy National Geographic Society.

Figure 48. Amalik Bay & islet just north of Takli Island in 1919 (E. Kolb) and 2005 (M. Jorgenson). This area received a meter or more of ashfall in 1912. Graminoids visible in Kolb's 1919 image were probably holdover plants that survived the ashfall. An herbaceous plant community has developed in the foreground, dominated by bluejoint, fireweed, chocolate lily *(Fritillaria camschatcensis),* seacoast angelica (*Angelica lucida)*, and paintbrush (*Castilleja* sp.). The rocky intertidal zone is little changed. 1919 photo courtesy National Geographic Society.

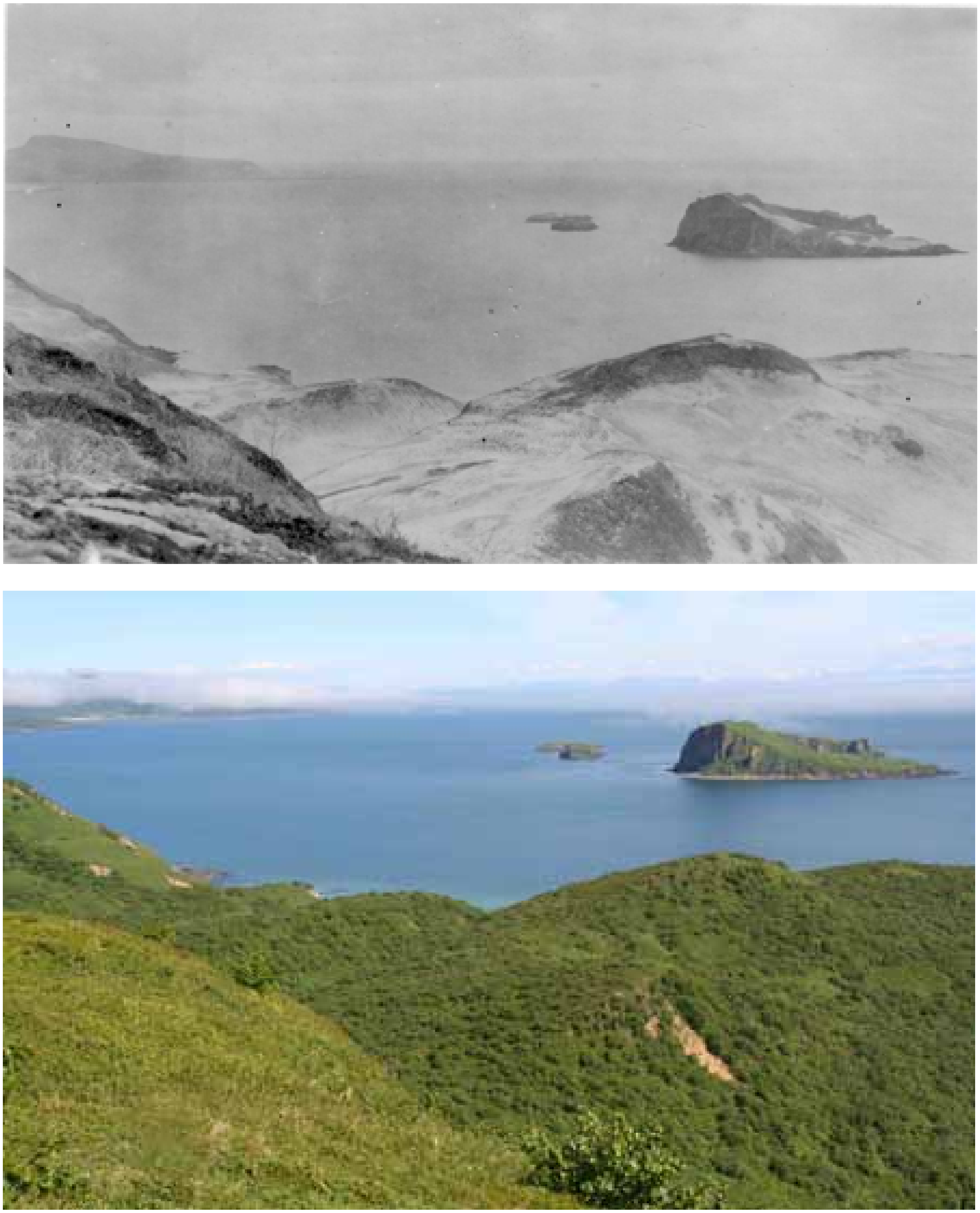

Figure 49. Coastal uplands and Shelikof Strait seen from the eastern entrance of Amalik Bay in 1919 (W. Henning) and 2005 (M. Jorgenson). This site was severely affected by 1912 ashfall. The 1919 image reveals that heavy tephra cover persisted on all but the steepest slopes and virtually no preexisting vegetation survived. Despite the lack of holdover vegetation, tall alder thickets and herbaceous meadows have established widely over the last 86 years. 1919 photo courtesy National Geographic Society.

Figure 50. Coastal uplands and Shelikof Strait seen from the eastern entrance of Amalik Bay in 1919 (W. Henning) and 2005 (M. Jorgenson). The 1919 image reveals only a small live patch of vegetation in the center of the knoll, probably alders that survived the ashfall. Despite the lack of holdover vegetation, tall alder thickets and a coastal meadow have established over the last 86 years. Retransported tephra is conspicuous on the small floodplain. 1919 photo courtesy National Geographic Society.

Figure 51. Entrance of Amalik Bay seen from the east in 1919 (W. Henning) and 2005 (M. Jorgenson). This site was severely affected by 1912 ashfall. The 1919 image reveals scattered patches of vegetation, probably composed of alders that survived the ashfall. Tall alder thickets have reestablished widely over the last 86 years and barren tephra is only visible in the coves at center right. 1919 photo courtesy National Geographic Society.

Figure 52. Alpine ridge between Amalik and Dakavak Bays, from an elevation of 725 m, in 1919 (W. Henning) and 2005 (M. Jorgenson). The 2005 vantage point was slightly adjusted to allow greater coverage of the foreground. This area was smothered in over a meter of tephra in 1912. Alpine tundra vegetation has recovered on steep, exposed slopes that have been stripped of tephra, but vegetation recovery has been slow where deposits have persisted. 1919 photo courtesy National Geographic Society.

Figure 53. Hidden Harbor seen from the south in 1919 (J. Sayre) and 2005 (M. Jorgenson). The Hidden Harbor area was among those most severely affected by 1912 ashfall. In 1919, surviving shrub thickets are conspicuous as dark patches on the pale ash deposits (lower left & right). These patches almost certainly represent holdover alder shrub. Tall alder scrub has reestablished across most of the area over the last 86 years. 1919 photo courtesy National Geographic Society.

Figure 54. The head of Hidden Harbor seen from mountainside to the northwest from an elevation of 335 m in 1929 (B. Hubbard) and a nearby location in 2005 (M. Jorgenson). Tephra deposits did not persist across much of the steep planar slope in the background, allowing much of the 1912 vegetation there to survive. Hubbard's image reveals that recovery of tall alder on the steep slope was already well underway in 1929. By 2005, vegetation recovery in the area is at an advanced stage, although persistent thick tephra deposits remain very sparsely vegetated. 1929 photo courtesy Santa Clara University.

Figure 55. The head of Hidden Harbor seen from mountainside to the northwest at 335 m elevation in 1929 (B. Hubbard) and a nearby location in 2005 (M. Jorgenson). This area was severely affected by 1912 ashfall. Hubbard's image reveals that recovery of coastal alder thickets on the steep slope was already well underway in 1929. By 2005, vegetation recovery in the area is at an advanced stage. 1929 photo courtesy Santa Clara University.

Figure 56. Cape Douglas seen from mainland, looking northeast, in 1904 (R. Stone) and 2005 (M. Jorgenson). Photo comparison illustrates channel migration and primary succession associated with the glacial streams in the background. No changes are evident in the foreground, where dominance of dwarf shrubs continues. 1904 photo courtesy USGS.

Figure 57. Lower Mageik Creek in canyon, looking downstream towards Katmai River valley, in 1917 (R. Griggs) and 2004 (G. Frost). The area appears little changed since Griggs' 1917 visit. 1912 ash and pumice deposits have been retransported from steep, exposed slopes and Mageik Creek has shifted on its constricted floodplain. As seen at many other locations in the area, vegetation recovery is most advanced along the margins of eroded pumice deposits. 1917 photo courtesy National Geographic Society.

Figure 58. The Katmai River and Barrier Range near the outlet of Katmai Canyon in 1917 (R. Griggs) and 2004 (G. Frost). Alders have reestablished at many locations which were barren in 1917, particularly on steep slopes where tephra deposits did not persist. It is likely that some 1912 alders survived burial. 1917 photo courtesy National Geographic Society.

Figure 59. Mt. Katmai seen from the Katmai River floodplain in 1918 (J. Sayre) and from a nearby vantage point in 2004 (G. Frost). Very little change is evident since Sayre's 1918 image as channel migration has prevented the establishment of any vegetation on the floodplain. New vegetation is apparent along the margins of eroded 1912 tephra deposits in the background. 1918 photo courtesy National Geographic Society.

Figure 60. Looking up Katmai Canyon at “Prospect Point” in 1919 (E. Kolb) and 2005 (M. Jorgenson). A large flood in 1915 retransported a large volume of colluvium from the landslide feature in the background. The Katmai River has cut down through these deposits and the general level of the active floodplain appears somewhat lower. Disturbance is continually renewed by channel migration on the active floodplain, except on the undisturbed terrace at right. It has been colonized by vegetation, although the river is beginning to undercut it. 1919 photo courtesy National Geographic Society.

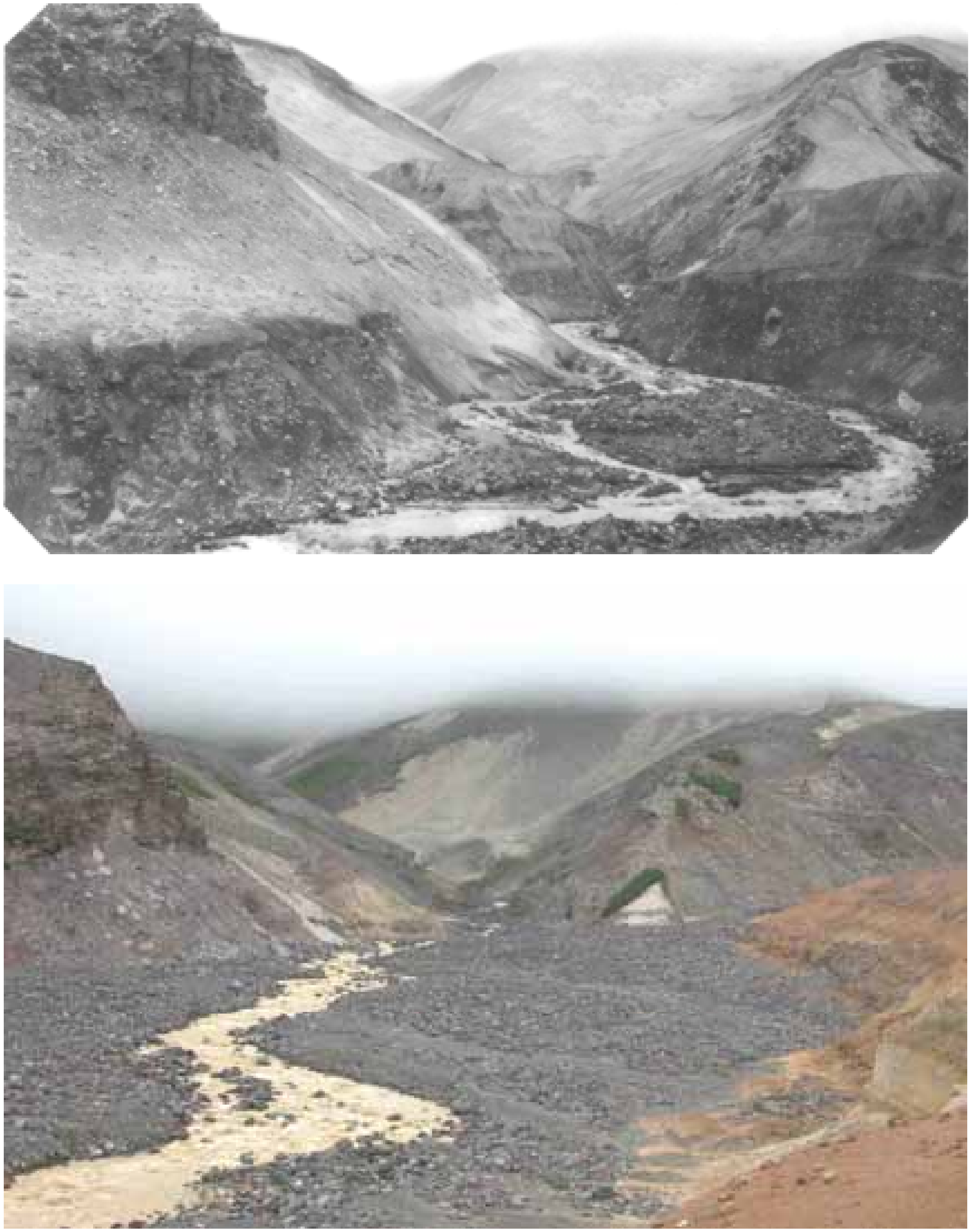

Figure 61. Stream at southern base of Mt. Katmai, seen from the cutbank of a colluvial tuff deposit west of Katmai Canyon, in 1923 (C. Yori) and a nearby location in 2004 (G. Frost). The reddish tuff seen at right of the 2004 image was deposited during a landslide on the southern slopes of Mt. Katmai in 1912. Over the 81 years since Yori's visit, the migrating stream has eroded part of the tuff deposit and Yori's vantage point no longer exists. Part of the 1923 tuff edge can be seen in the upper right of the 1923 image.

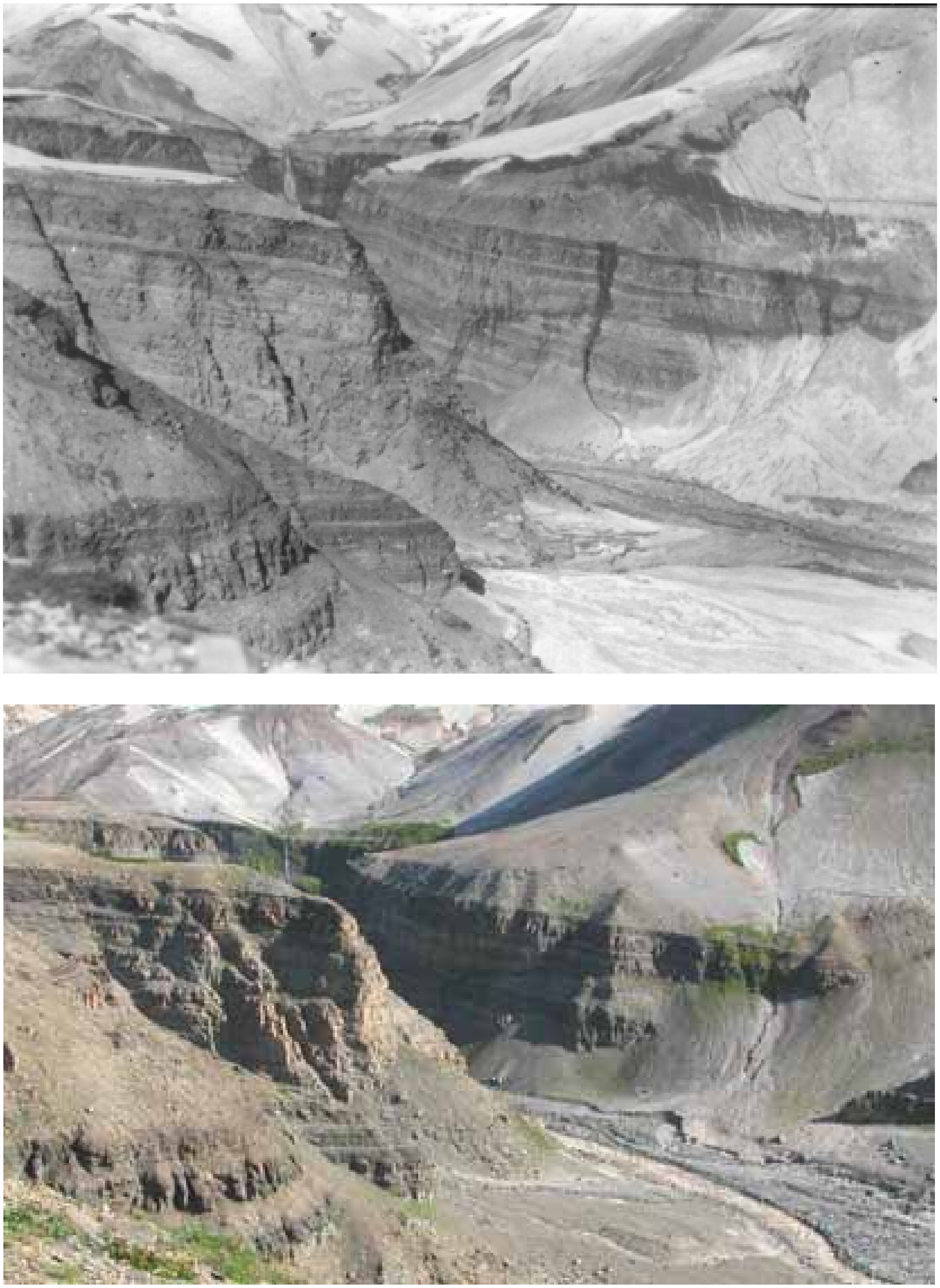

Figure 62. Looking east over lower Mageik Creek towards the base of Mt. Katmai in 1935 (B. Hubbard) and 2004 (G. Frost). Note the large mass of landslide colluvium at lower right. Vegetation recovery is limited to patchy microsites, generally where 1912 volcanic deposits have been stripped by slides and eolian processes. The barren floodplain of Mageik Creek is continually disturbed by channel migration and flood events. 1935 photo courtesy Santa Clara University.

Figure 63. Katmai River entering Katmai Canyon, looking upriver from the southern slopes of Mt. Katmai, in 1916 (D. Church) and from a similar vantage point farther upslope in 2004 (G. Frost). The river floodplain was nearly level following a large flood event in 1915, but the Katmai River has since cut down through landslide colluvium and alluvial deposits to form terraces. Terraces that have not been recently disturbed by channel migration and flooding are among the few surfaces in the area that support extensive vegetation. 1916 photo courtesy National Geographic Society.

Figure 64. Katmai Village site seen in 1916 (D. Church) and a 2005 aerial photograph (M. Jorgenson) from a nearby location. Ash-rich alluvium deposited by the braided Katmai River has buried the entire village site. Recovery of tall alder shrubs after 1912 ashfall is evident on the slopes of Mt. Pedmar in the background. 1916 photo courtesy National Geographic Society.

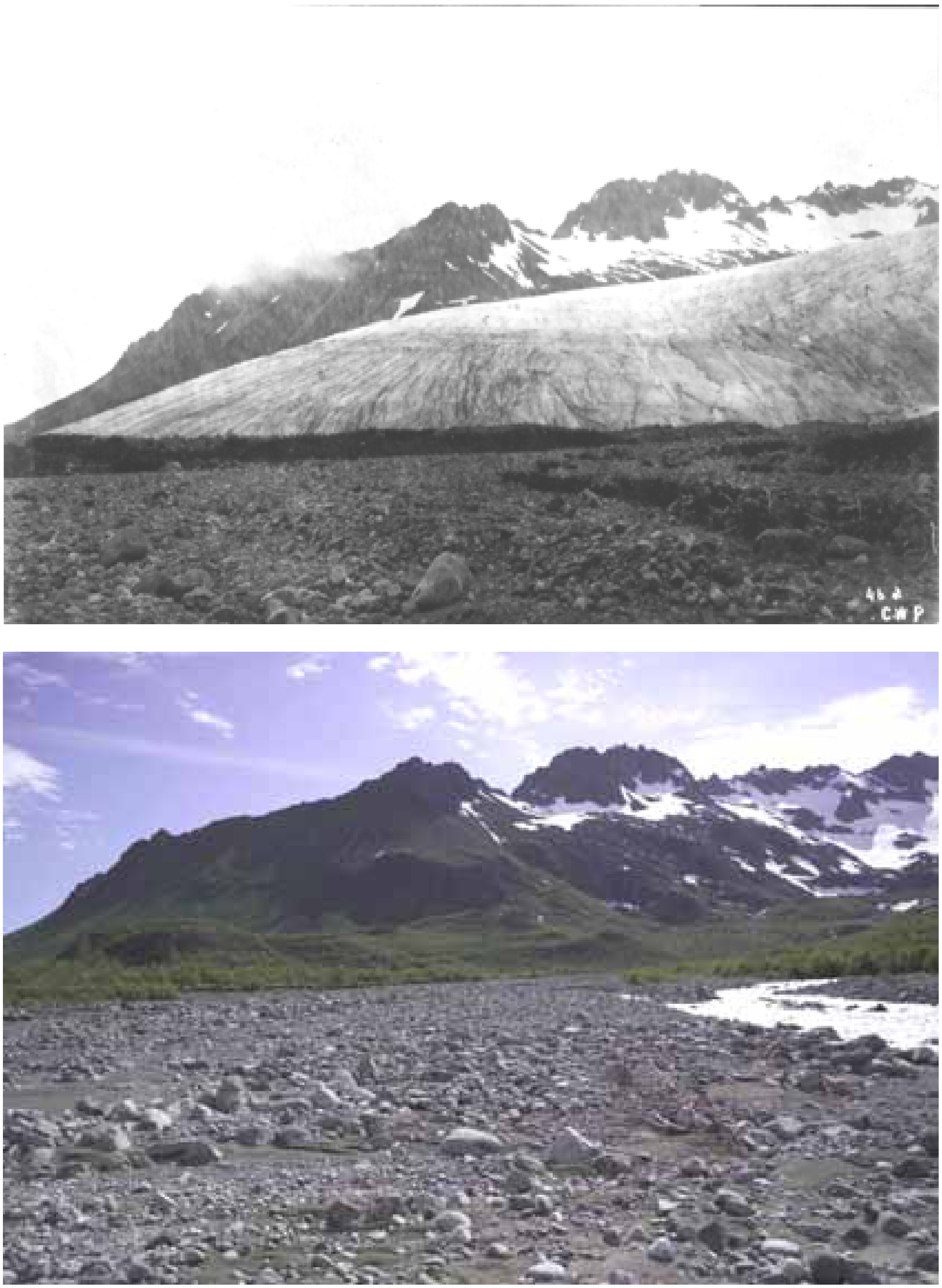

Figure 65. Unnamed glacier south of Cape Douglas seen in 1895 (C. Purington) and 2005 (M. Jorgenson). Purington’s photograph shows the glacier’s terminus at or near its maximal extent following the Little Ice Age. By 2005, it had retreated out of the field of view. Tall scrub has established widely on morainal surfaces, but not on the continually disturbed floodplain of the glacial stream. 1895 photo courtesy USGS.

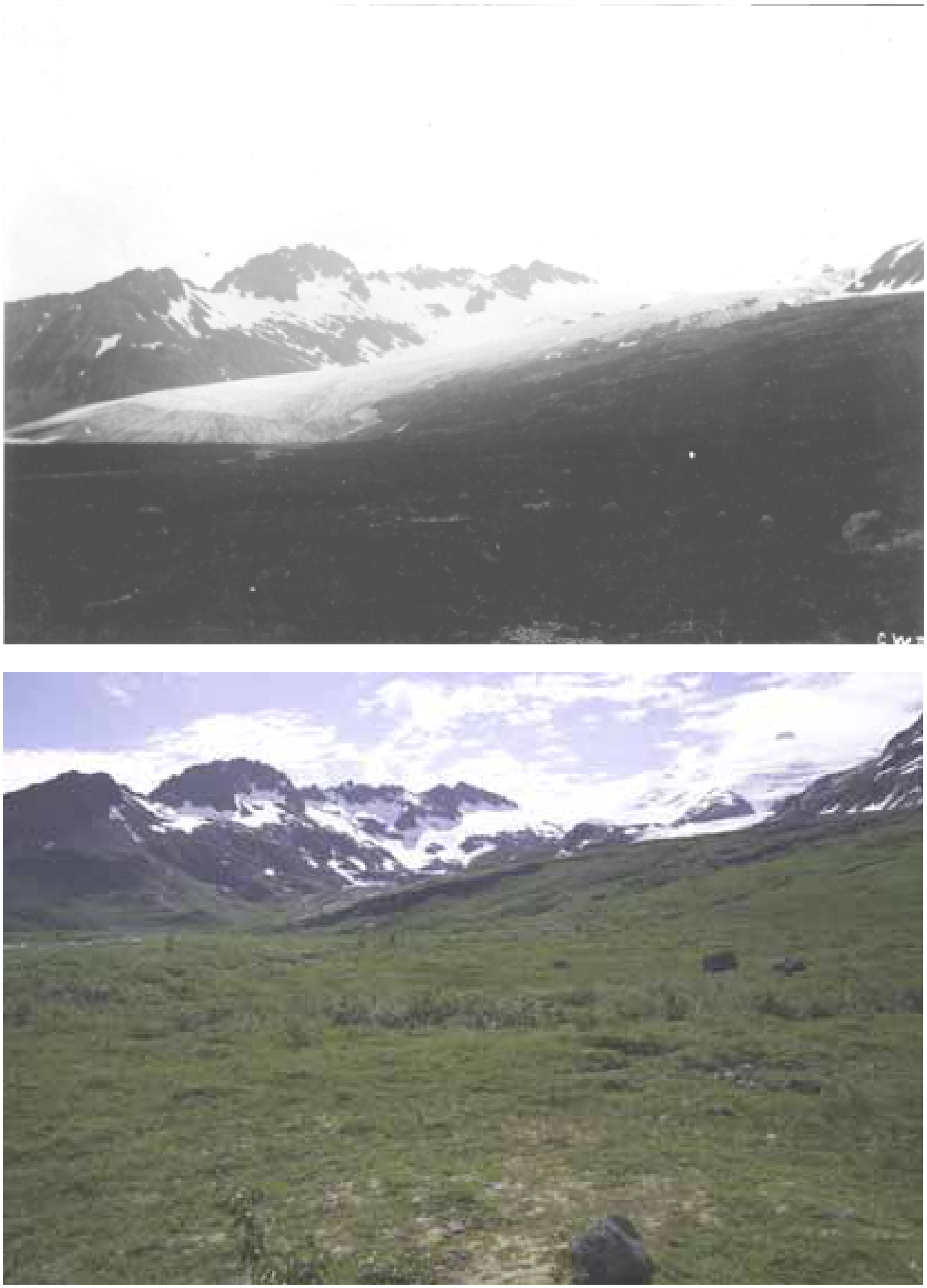

Figure 66. Unnamed glacier south of Cape Douglas seen in 1895 (C. Purington) and 2005 (M. Jorgenson). Comparison with Purington’s 1895 image reveals that this unnamed glacier has retreated about 2 km over the last century. Purington’s photograph shows the glacier at or near its maximal extent after the Little Ice Age. 1895 photo courtesy USGS.

Figure 67. Fourpeaked Mountain area seen from Cape Douglas in 1904 (R. Stone) and 2005 (M. Jorgenson). Comparison with Stone's 1904 image shows dramatic retreat of Fourpeaked Glacier (left) and an unnamed glacier (right). In 1904, both glaciers were near their maximal extent after the Little Ice Age. 1904 photo courtesy USGS.

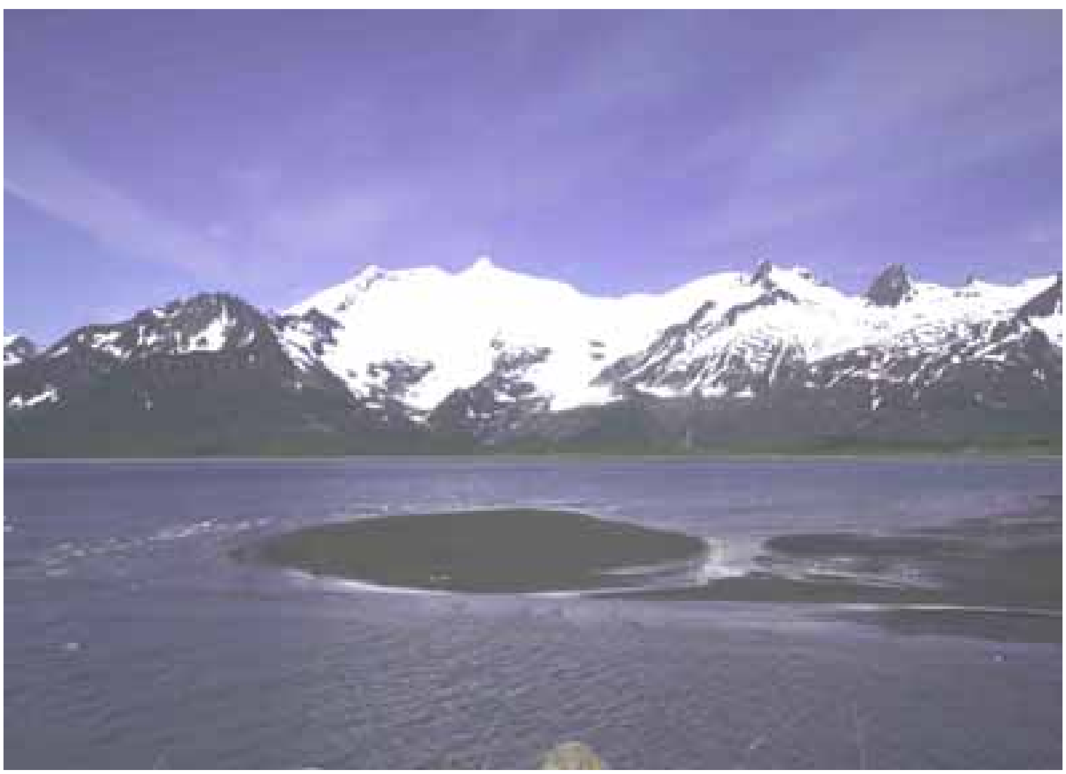

Figure 68. Mt. Douglas, looking west from the shoreline near Cape Douglas, in 1904 (R. Stone) and 2005 (M. Jorgenson). Like other glaciers in the area, the unnamed glacier below Mt. Douglas has retreated significantly over the last century. 1904 photo courtesy USGS.

Figure 69. Fourpeaked Mountain area, seen from southern side of Cape Douglas, in 1904 (R. Stone) and 2005 (M. Jorgenson). In 1904, Fourpeaked Glacier (background) was at or near the coast, representing its maximal extent after the Little Ice Age. It has retreated about 6 km over the last century. The rocky intertidal zone has not changed perceptibly. 1904 photo courtesy USGS.

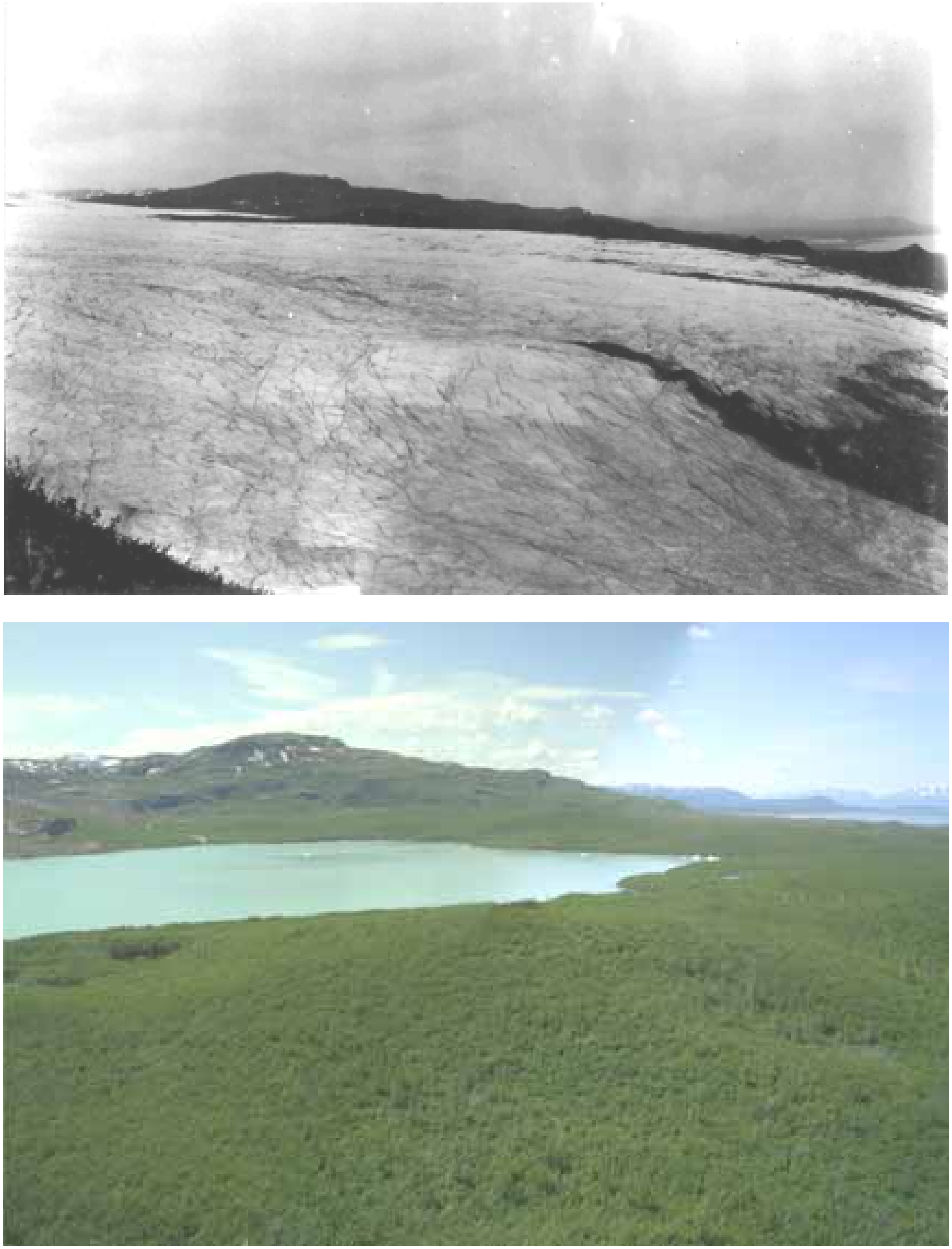

Figure 70. Spotted Glacier area looking west in 1904 (T. Stanton) and 2005 (M. Jorgenson). In 1904 the glacier was near its maximal extent following the Little Ice Age, but in the last century the glacier has retreated about 6 km. The young morainal surface has been colonized by alders and scattered trees, while the center of the valley is occupied by a moraine-dammed lake. Thaw of ice-cored moraine has formed several kettle ponds. 1904 photo courtesy USGS.

Figure 71. The northern two Knife Creek Glaciers, seen from cutbank of North Fork Knife Creek in 1954 (G. Schaller) and at a nearby location in 2004 (G. Frost). The original vantage point no longer exits as fluvial processes have eroded the cutbank Schaller used in 1954. The small Knife Creek glacier at left has retreated slightly, while the glacier at right is near the same position. Note the thick tephra deposits covering both glaciers. It is likely that the insulating effect of the ash and pumice has reduced seasonal ablation of these glaciers since 1912.

Figure 72. Two of the Knife Creek Glaciers, seen from western slope of Broken Mountain, in 1954 (G. Schaller) and from a similar position in 2004 (G. Frost). Comparison reveals little change in the terminus postions of the glaciers, although there may be some thinning. Mantled with thick tephra deposits in 1912, persistent ash & pumice have insulated these glaciers and have probably lessened rates of seasonal ablation.

Figure 73. Photos of unnamed glacial valley in the southwest corner of the Valley of Ten Thousand Smokes from 1918 (J. Sayre) and 2004 (G. Frost). The glacier has receded and prostrate vegetation has slowly begun to establish on limited portions of the bedrock valley bottom. The 1918 photo indicates that this glacier, unlike the relatively stable Knife Creek Glaciers east of Novarupta, did not receive thick tephra deposits during the 1912 eruption. 1918 photo courtesy National Geographic Society.

Figure 74. Naknek River near the lower end of Naknek Rapids, looking west, in 1918 (J. Sayre) and 2005 (G. Frost). Trees, primarily white spruce and Kenai birch, have expanded markedly in this area near King Salmon since Sayre's 1918 photograph. Very little change is evident on the Naknek River floodplain. The large spruce in the 2005 foreground is likely seen as a sapling in the 1918 image. 1918 photo courtesy National Geographic Society.

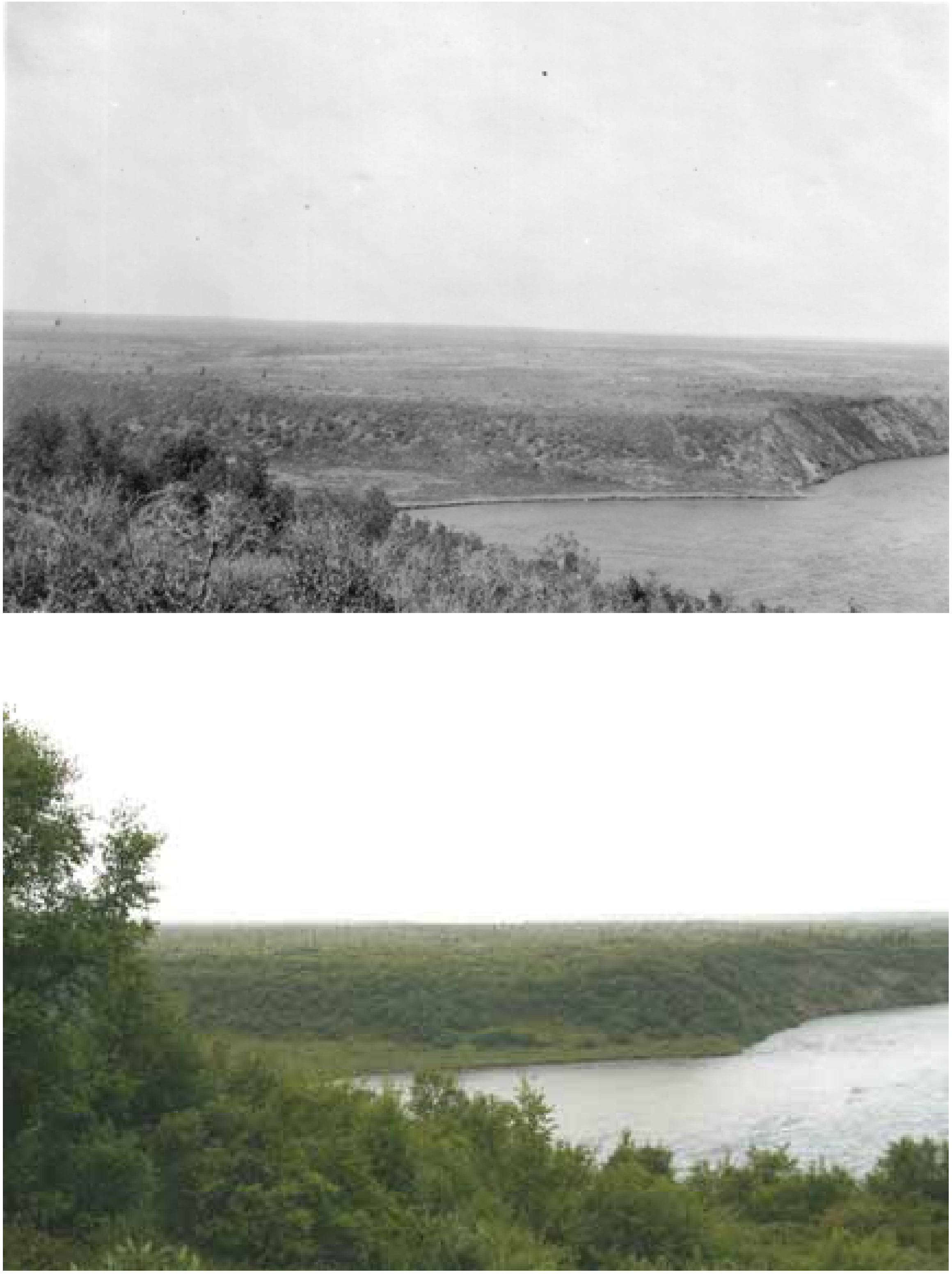

Figure 75. Looking south across Naknek River near lower Naknek Rapids in 1918 (J. Sayre) and 2005 (G. Frost). White spruce and Kenai birch trees have expanded dramatically in the King Salmon area since Sayre photographed this site in 1918. Sayre's photograph reveals sparse spruce trees on the opposite side of the Naknek River. 1918 photo courtesy National Geographic Society.

Figure 76. Naknek River from crest of bluff above “River Camp” public access site southeast of King Salmon, in 1918 (J. Sayre) and 2005 (G. Frost). Kenai birch and balsam poplar trees have become so dense on the bluff that it is now impossible to locate Sayre’s precise 1918 vantage point. Although it is possible that the clearing in the 1918 image was created by human disturbance, repeated photographs elsewhere in the area confirm that trees have become much more abundant in the King Salmon area over the last century. 1918 photo courtesy National Geographic Society.

Figure 77. Area northwest of Naknek River near lower Naknek Rapids in 1918 (P. Hagelbarger) and 2005 (G. Frost). White spruce and Kenai birch trees have expanded dramatically in the King Salmon area since Sayre photographed the site. White spruce saplings can be seen in the middle foreground of the 1918 image. 1918 photo courtesy National Geographic Society.

Figure 78. Area northeast of Naknek River, from vantage point just east of that shown in Figure 77, in 1918 (P. Hagelbarger) and 2005 (G. Frost). The dramatic expansion of trees here has obscured Hagelbarger's precise 1918 vantage point. White spruce and Kenai birch trees had already established on the knoll in the right background by 1918. 1918 photo courtesy National Geographic Society.

Figure 79. Granitic ridge south of Lake Grosvenor in 1919 (J. Sayre) and 2005 (M. Jorgenson), seen from an elevation of 300 m. Dramatic expansion of Kenai birch trees and tall alder scrub has occurred in the area over the last 86 years, obscuring most of the rock outcrops evident in the 1919 photo. 1919 photo courtesy National Geographic Society.

Figure 80. Overlooking Lake Grosvenor from granitic ridge at 366 m in 1919 (J. Sayre) and 2005 (M. Jorgenson). Cover of Kenai birch trees and alder shrubs has increased markedly in the area over the last 86 years, obscuring most of the rock outcrops evident in the 1919 photo. 1919 photo courtesy National Geographic Society.

Figure 81. Overlooking Lake Grosvenor from granitic ridge in 1919 (J. Sayre) and 2005 (M. Jorgenson). Kenai birch trees and alder shrubs now cover ~80% of the upland landscape and have obscured most of the rock outcrops visible in the original image. No change is evident in the lake shoreline. 1919 photo courtesy National Geographic Society.

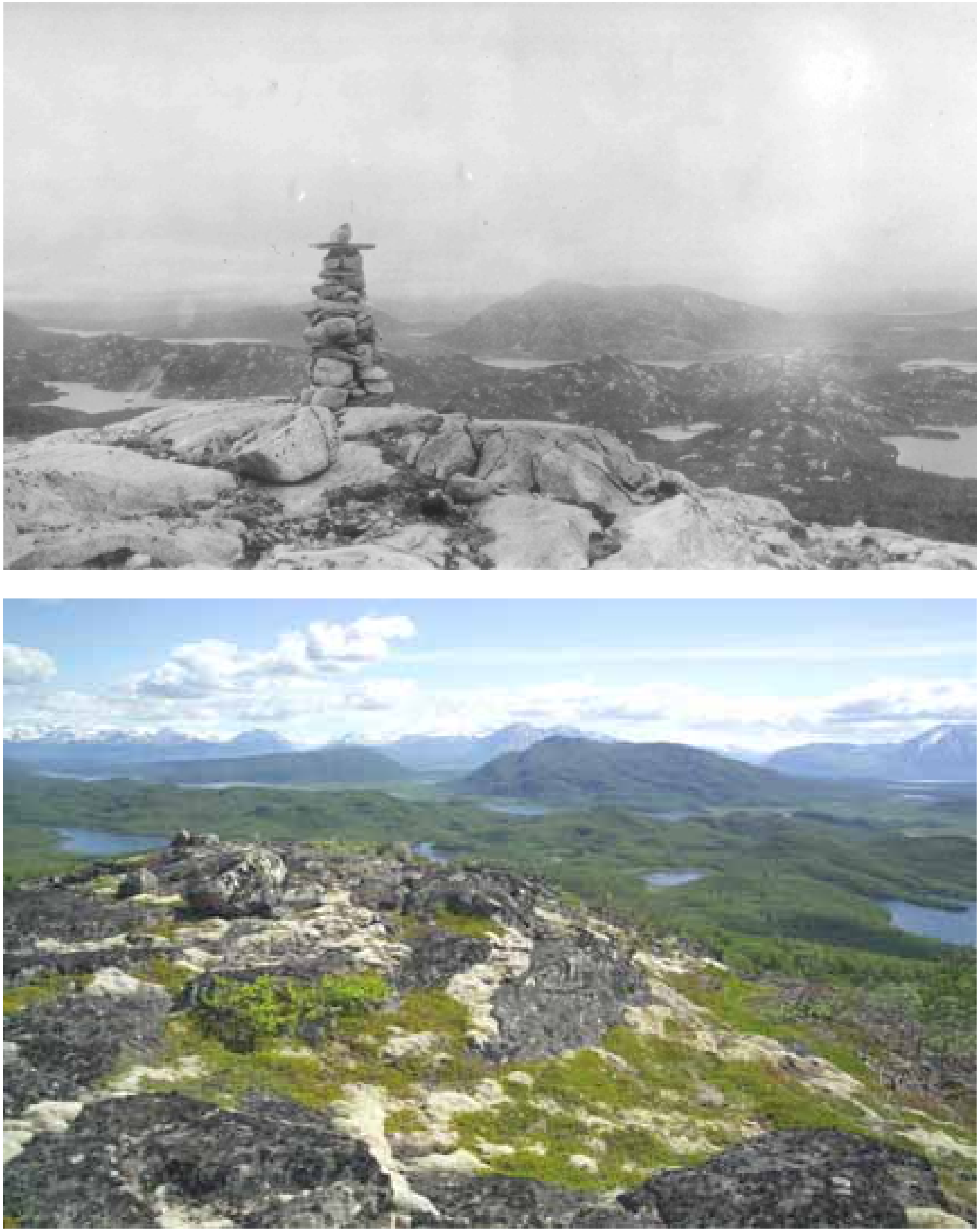

Figure 82. Overlooking area between Lake Grosvenor and lower Savonoski River in 1919 (J. Sayre) and 2005 (M. Jorgenson). Trees and shrubs have overgrown most of the rock outcrops visible in the original image. A lake bottom (far right background) has also drained and become vegetated. Absent in 1919, crustose lichens are now conspicuous on the rocks around Sayre's toppled cairn. This almost certainly represents recovery after disturbance rather than expansion. A possible cause of lichen mortality was acid rain following the eruption of Novarupta in 1912. 1919 photo courtesy National Geographic Society.

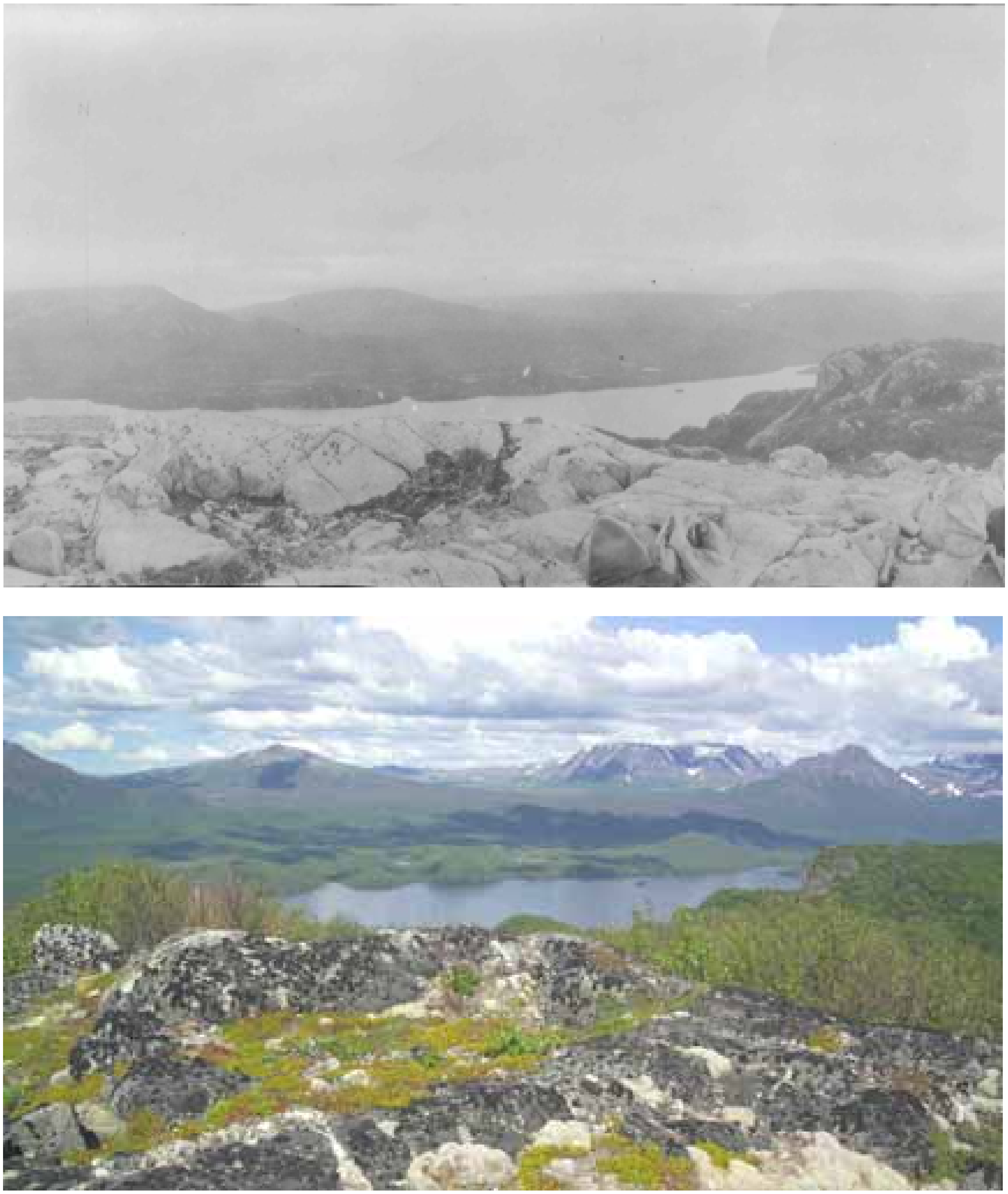

Figure 83. Panoramic view of Lake Grosvenor area from granitic ridge in 1919 (J. Sayre) and 2005 (M. Jorgenson). Expansion of birch trees and alder shrubs is evident on the low ridge at right. In 1919, the foreground rocks are virtually free of crustose lichens, while in 2005 lichens (mostly *Umbilicaria* spp.) are prominent. This almost certainly represents recovery after disturbance rather than expansion. A possible cause of lichen mortality was acid rain following the eruption of Novarupta in 1912. 1919 photo courtesy National Geographic Society.

Figure 84. Overlooking Bay of Islands area from granite ridge south of Lake Grosvenor in 1919 (J. Sayre) and 2005 (M. Jorgenson). Significant expansion of trees and tall shrubs is evident since 1919 and most granitic outcrops have been obscured by vegetation. A lake in the left background has partially drained and much of its former bed has become vegetated. 1919 photo courtesy National Geographic Society.

Figure 85. Uplands northeast of Ikagluik Creek at an elevation of 442 m in 1919 (J. Sayre) and 2005 (M. Jorgenson). Tall shrubs, chiefly alder, Sitka willow *(Salix sitchensis)*, and red elderberry (*Sambucus callicarpa)*, have expanded dramatically over an 86 year period, although it is not clear if this represents shrub expansion or recovery after disturbance such as ashfall or fire. The 1919 image reveals prostrate vegetation with some overtopping dead shrub stems, along with scattered patches of 1912 ashfall. A portion of the 1919 active floodplain (far left, next to the oxbow lake) has become vegetated. 1919 photo courtesy National Geographic Society.

Figure 86. Uplands northeast of Ikagluik Creek at an elevation of 442 m in 1919 (J. Sayre) and 2005 (M. Jorgenson). Tall shrubs have expanded dramatically over the 86 year interval, although it is not clear if this represents elevational expansion or recovery after disturbance such as ashfall or fire. The 1919 image reveals a mixture of dead and live shrubs and patches of 1912 ashfall. 1919 photo courtesy National Geographic Society.

Figure 87. Looking east toward Mt. Kubugakli from an elevation of 400 m in 1922 (W. Smith) and 2005 (M. Jorgenson). Tall shrub thickets, probably dominated by alder, can be recognized as dark patches on the middle and lower mountain slopes in the 1922 image. Comparison reveals that shrub thickets are more widely established in the subalpine zone and along the creek at lower center. Coverage of alpine tundra also appears to have expanded on rocky upper slopes, particularly on the spur ridge at center. 1922 photo courtesy USGS.

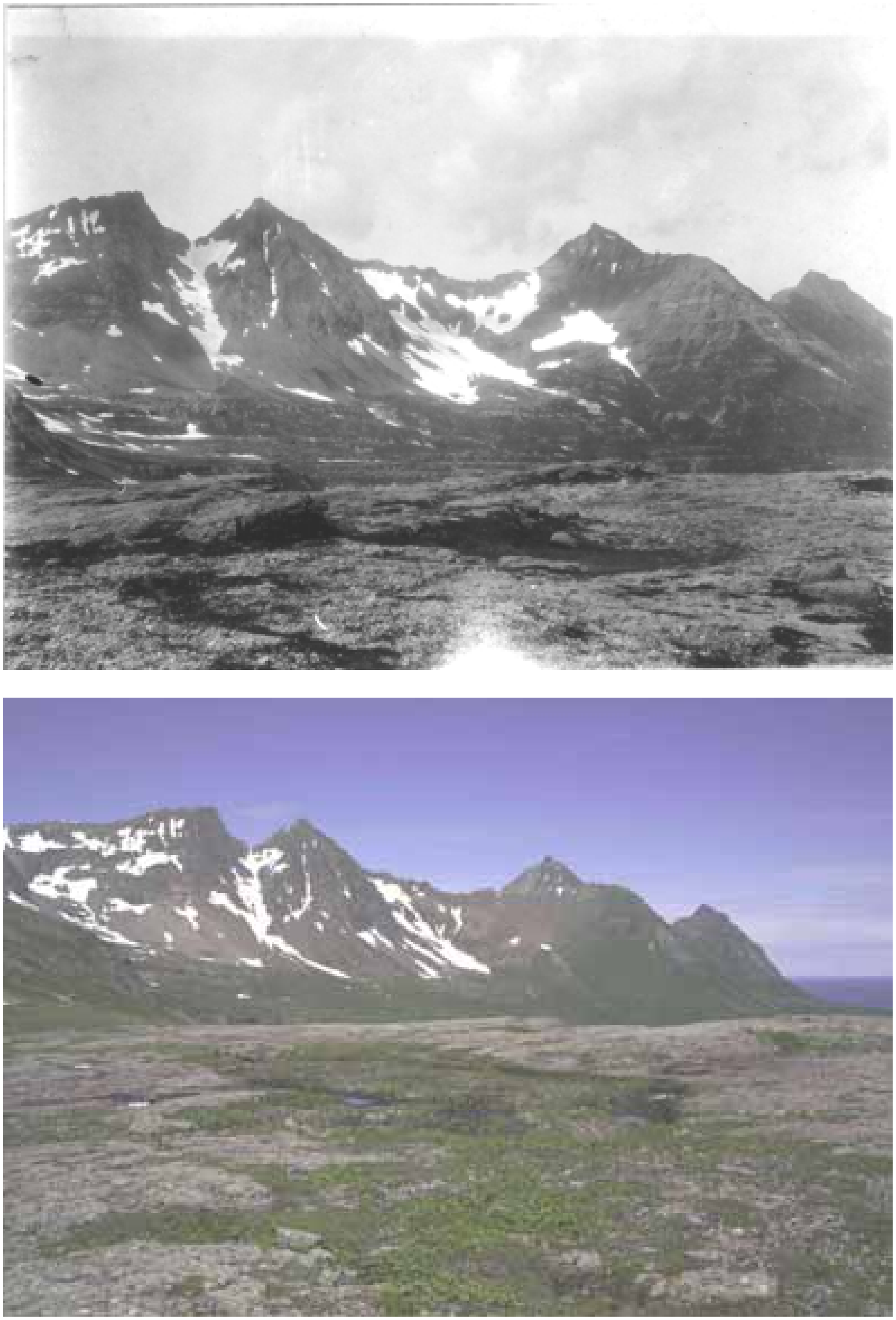

Figure 88. Coastal mountains west of Cape Douglas, seen in 1904 (R. Stone) and 2005 (M. Jorgenson). Comparison indicates the stability of dwarf scrub tundra at this exposed site at an elevation of about 244 m. No changes are evident in the background. 1922 photo courtesy USGS.

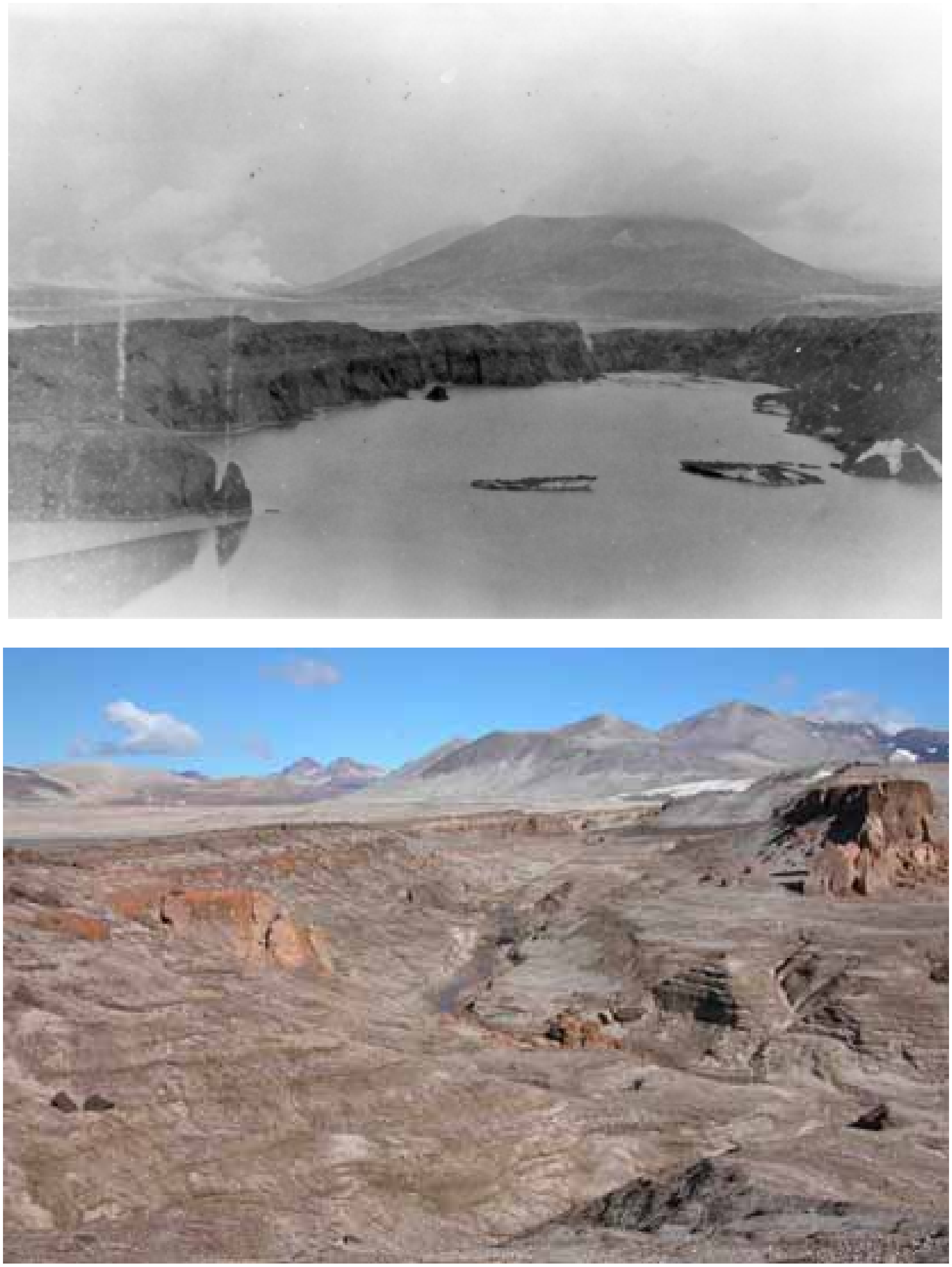

Figure 89. Looking east over a large fissure in the southwestern corner of The Valley of Ten Thousand Smokes in 1917 (R. Griggs) and 2004 (G. Frost). Contraction of 1912 pyroclasts formed several large fissures along the southwest margins of the valley. The fissure at this site formed the bed of a short-lived lake. As at many sites in the area, vegetation has gained little foothold on 1912 ignimbrite deposits and gully erosion is widespread. 1917 photo courtesy National Geographic Society.

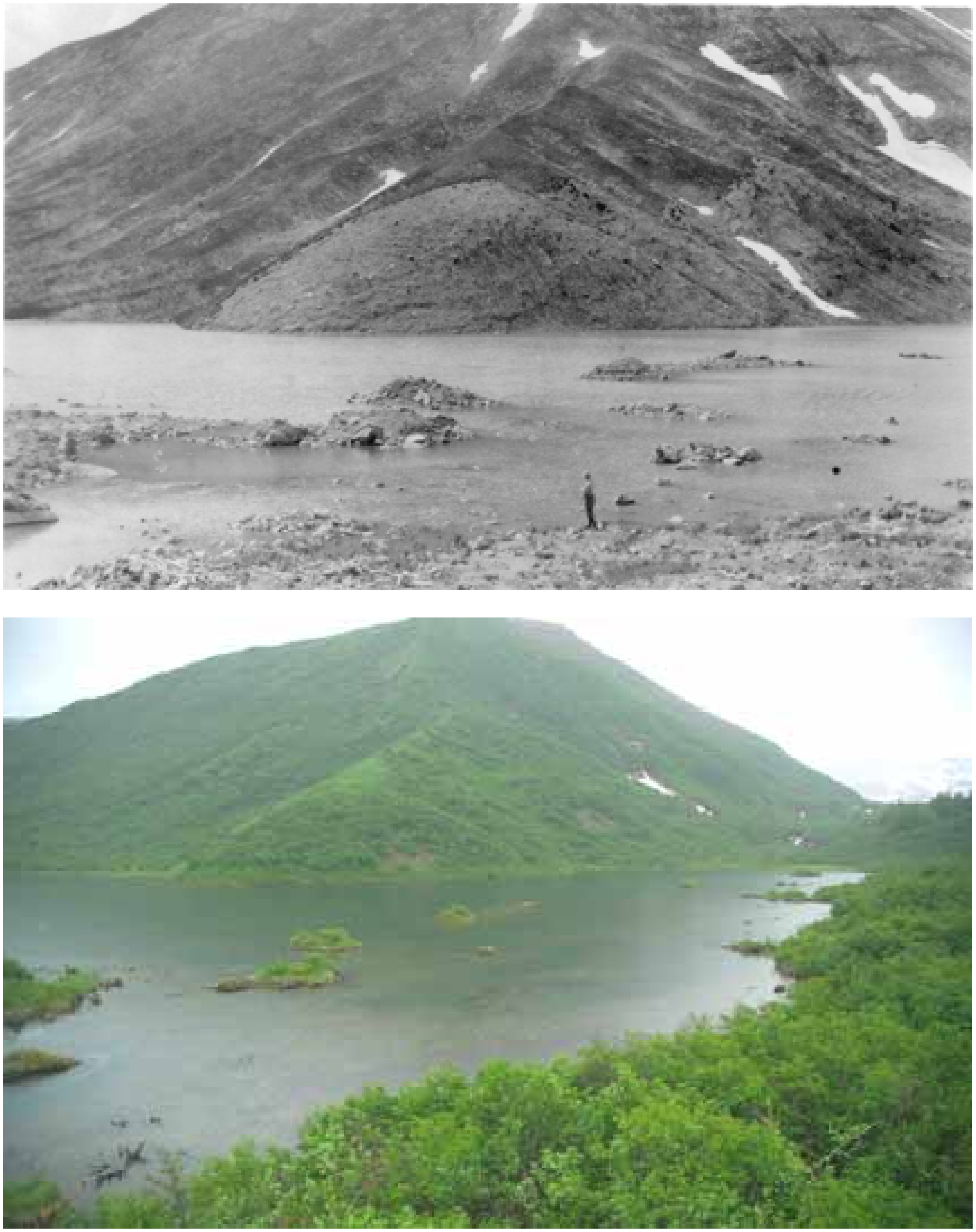

Figure 90. Pond along the southern margin of the Mageik Landslide in 1919 (R. Griggs) and 2005 (M. Jorgenson). The pond bottom and adjacent lowlands are young surfaces composed of landslide colluvium. Griggs reported that Mageik Landslide colluvium retained large amounts of surface organic material, a factor that likely explains the advanced stage of vegetation recovery here compared to other landslides in the area which left behind inorganic surfaces. The base of the mountain was scoured by colluvium during the landslide, but this surface has also revegetated. The pond islets and shoreline are largely unchanged. 1919 photo courtesy National Geographic Society.

Figure 91. Iliuk Arm and mouths of Ukak and Savonoski Rivers (right) from ridge northeast of Mt. Katolinat in 1918 (J. Sayre) and 2005 (M. Jorgenson). The level of disturbance to the forested lowlands following the 1912 eruption is difficult to assess from the 1918 photo, although ashfall is apparent in the nonforested areas. Copious volcanic sediments deposited by the Ukak River since 1912 have enlarged the river delta. A formerly forested area at far right of the 1918 image appears to have been buried by alluvial deposits. 1918 photo courtesy National Geographic Society.

Figure 92. Mt. Mageik and middle Mageik Creek, seen from the northern slopes of Observation Mountain, circa 1917 (D. Church) and 2004 (G. Frost). Since Church's photograph, willows have colonized much of the floodplain of Mageik Creek (foreground). In the early 1950s, a series of lava flows emerged from a new vent on the western slopes of Trident Volcano. Some of this lava reached the valley of Mageik Creek and can be seen at right. 1917 photo courtesy National Geographic Society.

Figure 93. Looking east up Katmai River between the Katmai Lakes in 1917 (D. Church) and 2005 (M. Jorgenson). This area was severely affected by a series of disturbance events associated with ashfall, flooding, and landslides following the Great Eruption of 1912. Remarkably little change is evident on the colluvial surface and primary succession is occurring very slowly. The river channel in the middle foreground has migrated slightly. 1917 photo courtesy National Geographic Society.

Figure 94. Upper Katmai Canyon circa 1917 (C. Maynard) and 2004 (G. Frost) seen from the southern slopes of Mt. Katmai. Following a large landslide on the flank of Mt. Katmai (left; outlined in 1917 photo), colluvium temporarily dammed the upper Katmai River (center). This feature was largely unchanged in 2004, but some of the colluvium to the right has been eroded and the river floodplain has widened and deepened. Tall alder shrub and alpine tundra vegetation is now present on the canyon walls at right, but very little vegetation has established elsewhere. 1917 photo courtesy National Geographic Society.

Figure 95. A site on the Mageik Landslide in 1917 (R. Griggs) and 2005 (M. Jorgenson). Griggs' image reveals that graminoids were already establishing on the landslide debris in 1917. In less than 90 years, the site has been completely vegetated by tall willows (concealing boulders) and graminoids. In contrast to other landslides associated with the 1912 eruption, Griggs reported that Mageik Landslide colluvium was composed of intermixed boulders, mineral soil, and retransported organic material. The retention of substantial surface organic material appears to have promoted rapid recovery of vegetation. 1917 photo courtesy National Geographic Society.

Figure 96. Stream on the Mageik Landslide in 1919 (R. Griggs) and 2005 (M. Jorgenson). Griggs reported that several irregular streams occurred on the surface of the landslide that “have not even cut beds for themselves in the gravelly debris.” Although vegetation recovery has advanced at a rapid pace on the Mageik Landslide, the configuration of this stream is remarkably similar to what Griggs saw in 1919. 1919 photo courtesy National Geographic Society.

Figure 97. Cape Douglas area seen from mainland, looking east, in 1904 (R. Stone) and 2005 (M. Jorgenson). Most coastal landforms have remained stable, although a spit in front of the cove at right center has shifted position since 1904. Some of the mainland ponds shrank or disappeared. 1904 photo courtesy USGS.

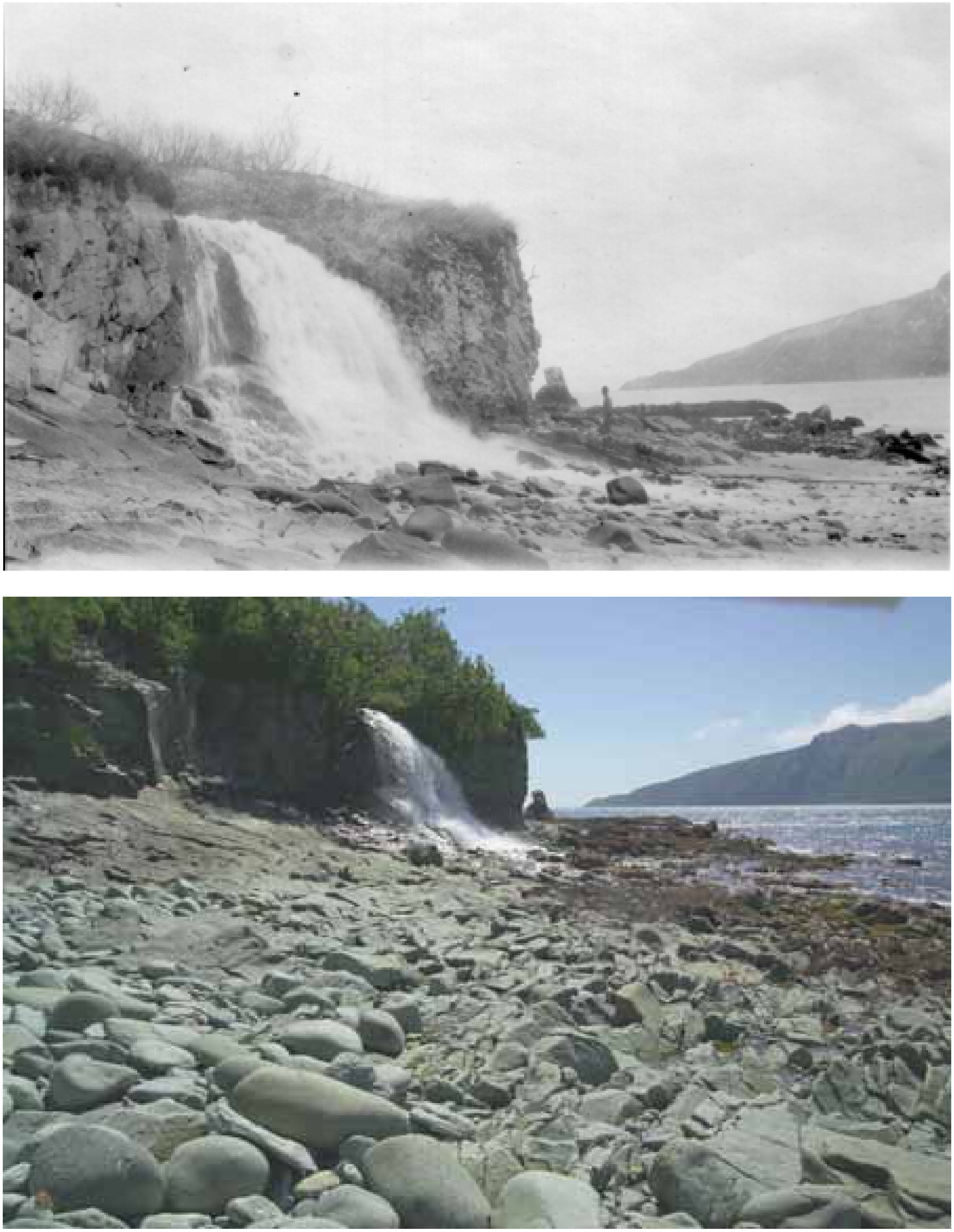

Figure 98. Waterfall entering Kuliak Bay in 1919 (P. Hagelbarger) and 2005 (M. Jorgenson). The 1919 image reveals dead tall shrub vegetation partially buried by 1912 tephra along the cliff edge. Tall shrubs have since reestablished here. The rocky intertidal zone, sea stack, and the waterfall do not appear to have changed appreciably. 1919 photo courtesy National Geographic Society.

Figure 99. Effects of coastal uplift from the 1964 earthquake is illustrated by photographs from 1921 (F. Moffit) and 2004 (M. Jorgenson) at Seal Spit in Chinitna Bay, near Lake Clark NP&P. Development of a lush coastal meadow dominated by the Lyngbyei's sedge (*Carex lyngbyei)* and the establishment of a few scattered Sitka spruce on the spit have occurred. 1921 photo courtesy USGS.

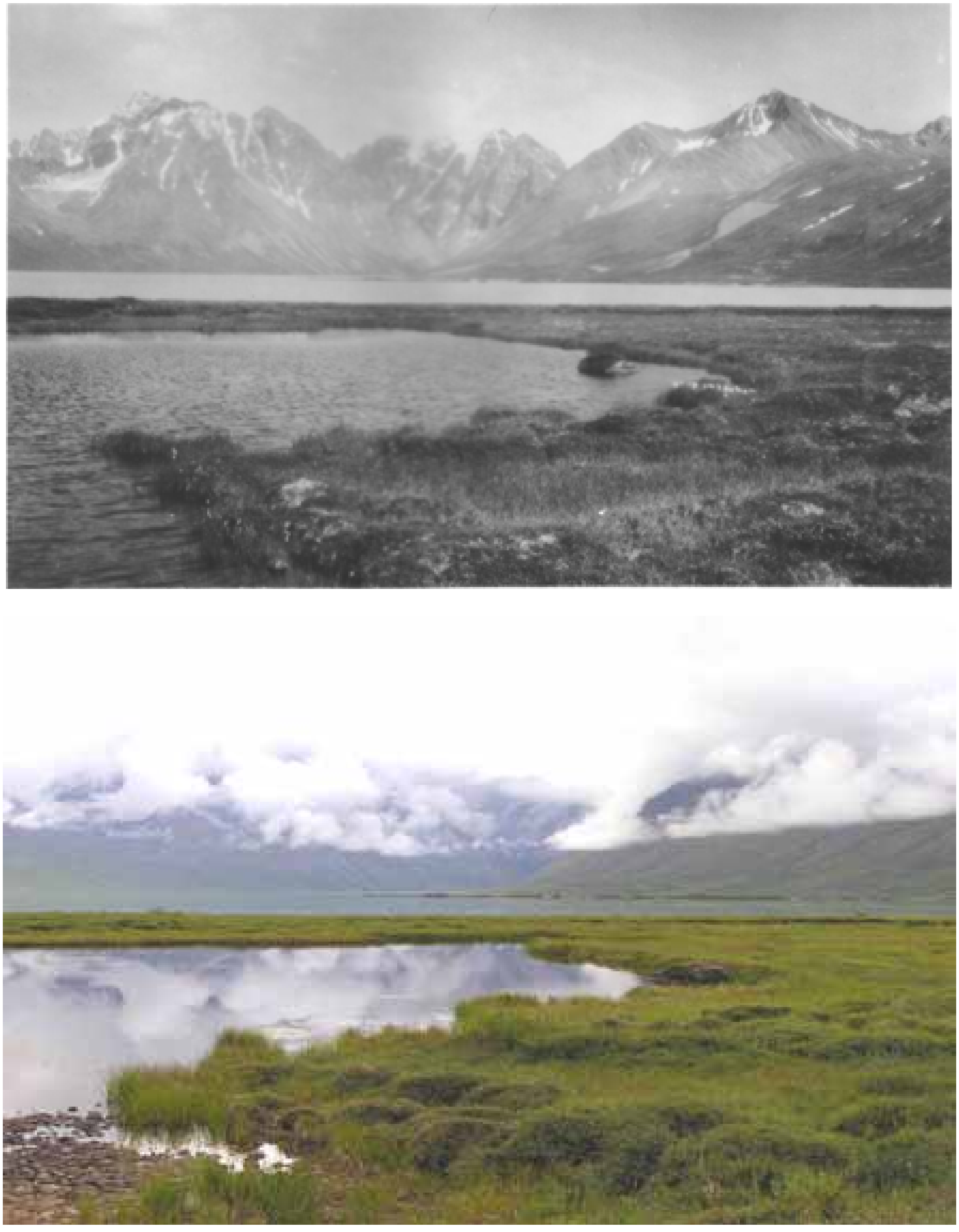

Figure 100. Panorama of Turquoise Lake area in 1929 (S. Capps) and 2004 (M. Jorgenson). The foreground sedge-dominated vegetation with dwarf shrubs on hummocks has not changed since Capps' 1929 visit, although paludification appears to be occurring along the nearby shoreline as vegetation slowly colonizes shallow water. Trees and tall shrubs have not established at this 772 m site. 1929 photo courtesy USGS.

Figure 101. Continuation of panorama of Turquoise Lake area in 1929 (S. Capps) and 2004 (M. Jorgenson). No striking changes are evident at this 772 m site, although vascular plant cover appears to be somewhat denser in the middle foreground, where pale patches in the 1929 photo indicate greater cover of rocks and lichens. 1929 photo courtesy USGS.

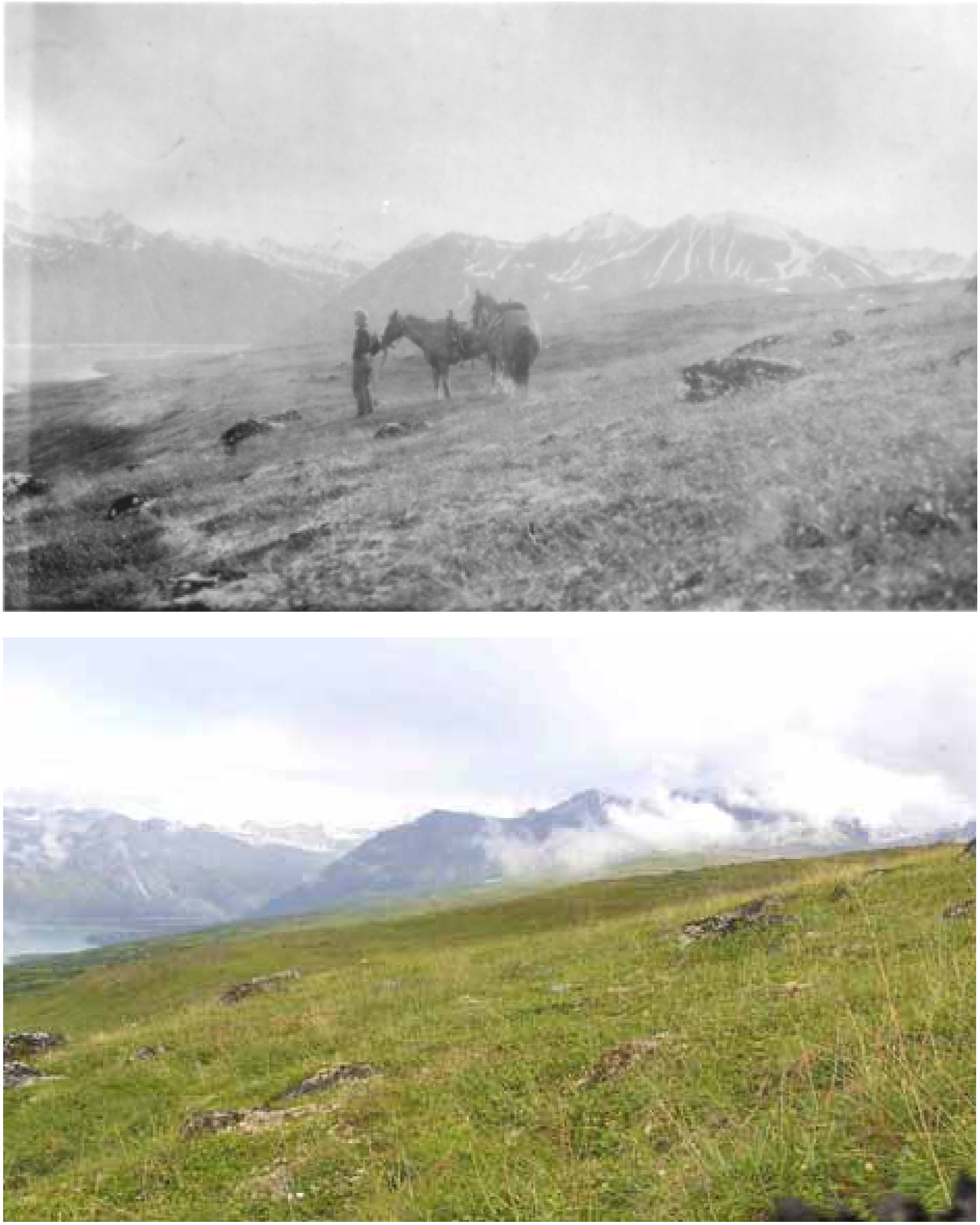

Figure 102. Panoramic view of Telaquana Lake area from morainal ridge at 823 m in 1929 (S. Capps) and 2004 (M. Jorgenson). Comparison reveals little vegetation change. Dwarf birch (*Betula nana*) may have formed a denser ground cover, but there has been little change in height. 1929 photo courtesy USGS.

Figure 103. Continuation of panorama of Telaquana Lake area in 1929 (S. Capps) and 2004 (M. Jorgenson). Tall shrub thickets appear to have expanded on the slopes at lower right. Spruce trees were already present along the lake shoreline in 1929. 1929 photo courtesy USGS.

Figure 104. Continuation of panorama of Telaquana Lake area in 1929 (S. Capps) and 2004 (M. Jorgenson). Tall shrub thickets appear to have expanded on the foreground slopes, although it is difficult to determine the extent of spruce trees in the 1929 photo. Spruce trees were already present along the lake shoreline in 1929. 1929 photo courtesy USGS.

Figure 105. Telaquana Lake area in 1929 (S. Capps) and 2004 (M. Jorgenson). Barren surfaces on the steep bluff in the middle distance of the 1929 photo have become vegetated by shrubs. Also, there is much less barren ground visible on the floodplain of the Telaquana River. Little change is evident in foreground dwarf scrub tundra at this 843 m elevation site. 1929 photo courtesy USGS.

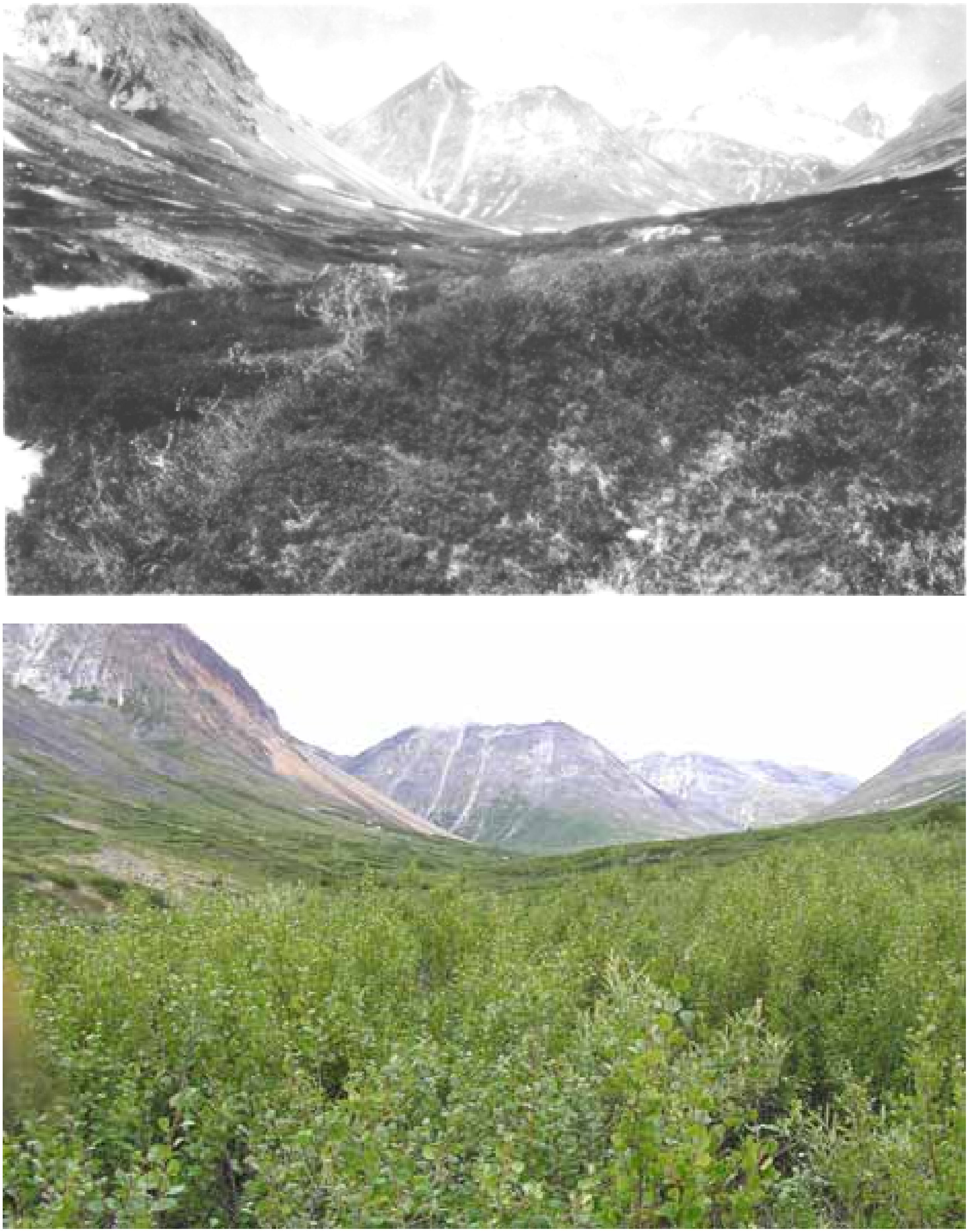

Figure 106. Looking west towards Merrill Pass from the upper Another River valley in 1928 (S. Capps) and 2004 (M. Jorgenson). Comparison reveals no dramatic vegetation changes at this site at about 2700 ft. Willow and birch shrubs may have become taller and denser. 1928 photo courtesy USGS.

Figure 107. Glacial valley at head of Another River in 1928 (S. Capps) and at a nearby location in 2004 (A. Bennett). Differing perspectives and seasonal snow in Capps' 1928 image makes it difficult to confirm change in the glacier, but it appears that it has receded markedly. Note the recent terminal moraine in the right background of the 2004 image. At an elevation of 854 m, this site remains above treeline. 1928 photo courtesy USGS.

Figure 108. Looking down Merrill River valley south of Goldpan Peak at an elevation of 613 m in 1928 (S. Capps) and 2004 (A. Bennett). Shrubs have colonized landslide colluvium at left and they appear to be taller and more abundant in the valley than when the Capps party camped here in 1928. It is not clear if the spruce trees at far right of the 2004 image were present in 1928. 1928 photo courtesy USGS.

Figure 109. Looking northeast from unnamed peak north of Little Lake Clark in 1909 (F. Katz) and 2004 (M. Jorgenson). Comparison with Katz's 1909 image reveals little change in dwarf scrub & lichen-dominated alpine tundra at this 700 m site, although a few more Krummholz spruce appear to have established. 1909 photo courtesy USGS.

Figure 110. Photographs from 1909 (F. Katz) and 2004 (M. Jorgenson) reveal substantial channel migration on the floodplain of the Tlikakila River over a 95-year period. Note reconfiguration of the large island (left foreground) and revegetation of the adjacent mid-channel bar. Behind the island, the left side of the floodplain has stabilized and become vegetated. Other large mid-channel bars also have become vegetated. 1909 photo courtesy USGS.

Figure 111. Slope Mountain seen from the Johnson River floodplain in 1920 (F. Moffit) and at a nearby location in 2004 (M. Jorgenson). The lack of permanent foreground features prevented exact replication of the historical vantage point, but channel migration clearly continues to renew disturbance on the floodplain of this glacial river. Tall alder thickets still dominate the subalpine zone in the background, except on unstable slopes where rockslides periodically renew disturbance. 1920 photo courtesy USGS.

Figure 112. Looking upriver from lower Merrill River valley in 1928 (S. Capps) and 2004 (M. Jorgenson). Continual channel migration of the glacial river has frequently renewed disturbance on the floodplain. Capps' image shows that spruce trees were already present on the floodplain and mountain slope at left in 1928. Large colluvial deposits in the background remain largely barren. 1928 photo courtesy USGS.

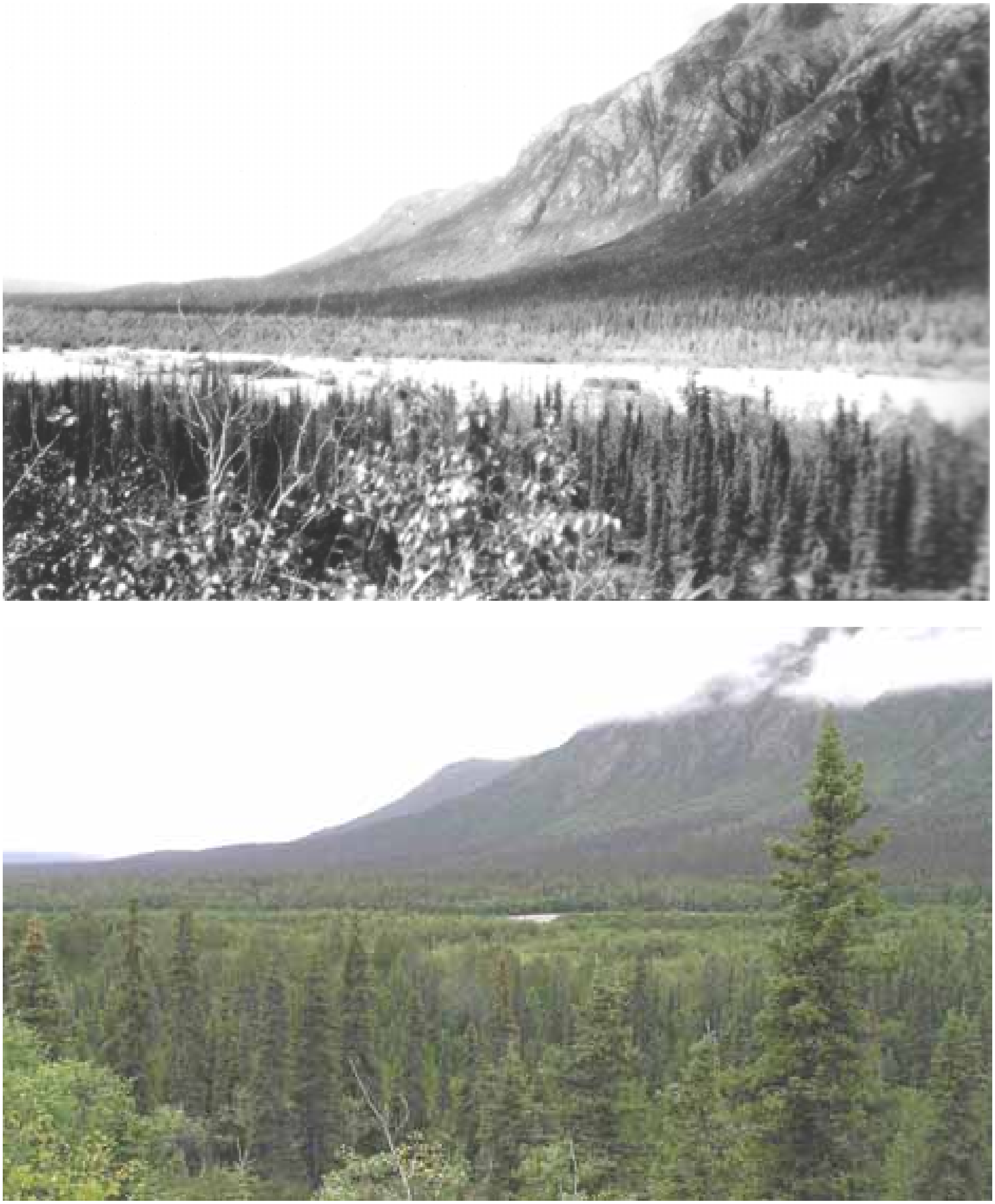

Figure 113. Looking down Stony River valley from near its confluence with Tired Pup Creek in 1928 (S. Capps) and 2004 (M. Jorgenson). Many of the formerly barren floodplain sites visible here have vegetated since 1928, although channel migration continues to renew disturbance nearby. Spruce trees were already well established here at about 366 m and the area has not experienced fire in the recent past. 1928 photo courtesy USGS.

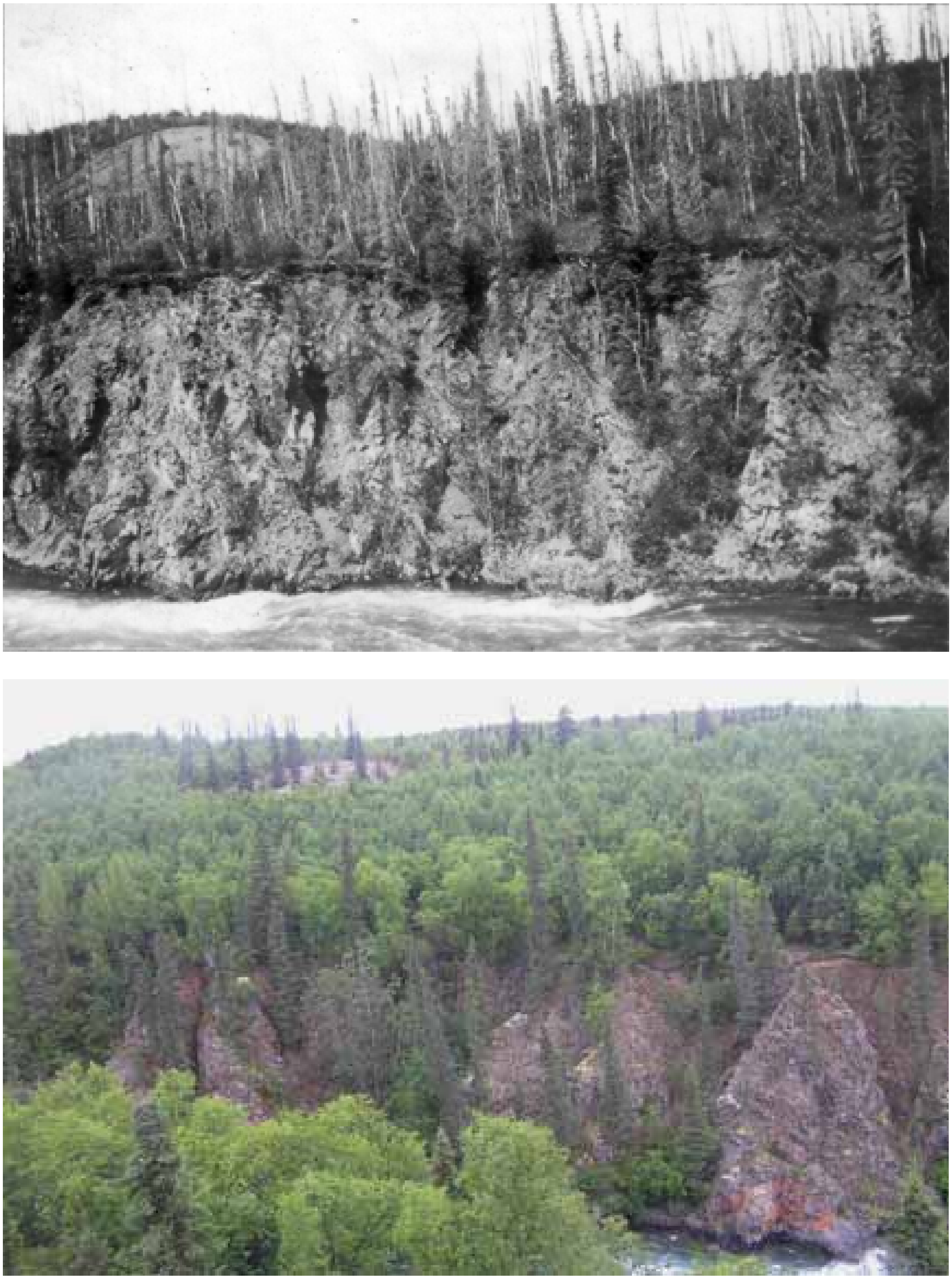

Figure 114. Gorge below Tanalian Falls seen from south bank of Tanalian River in 1909 (F. Katz) and a nearby location in 2004 (M. Jorgenson). Photo comparison illustrates plant succession after a fire shortly before 1909. Scattered large white spruce trees in the background survived the fire and overtop paper birches that are about 90 years old. 1909 photo courtesy USGS.

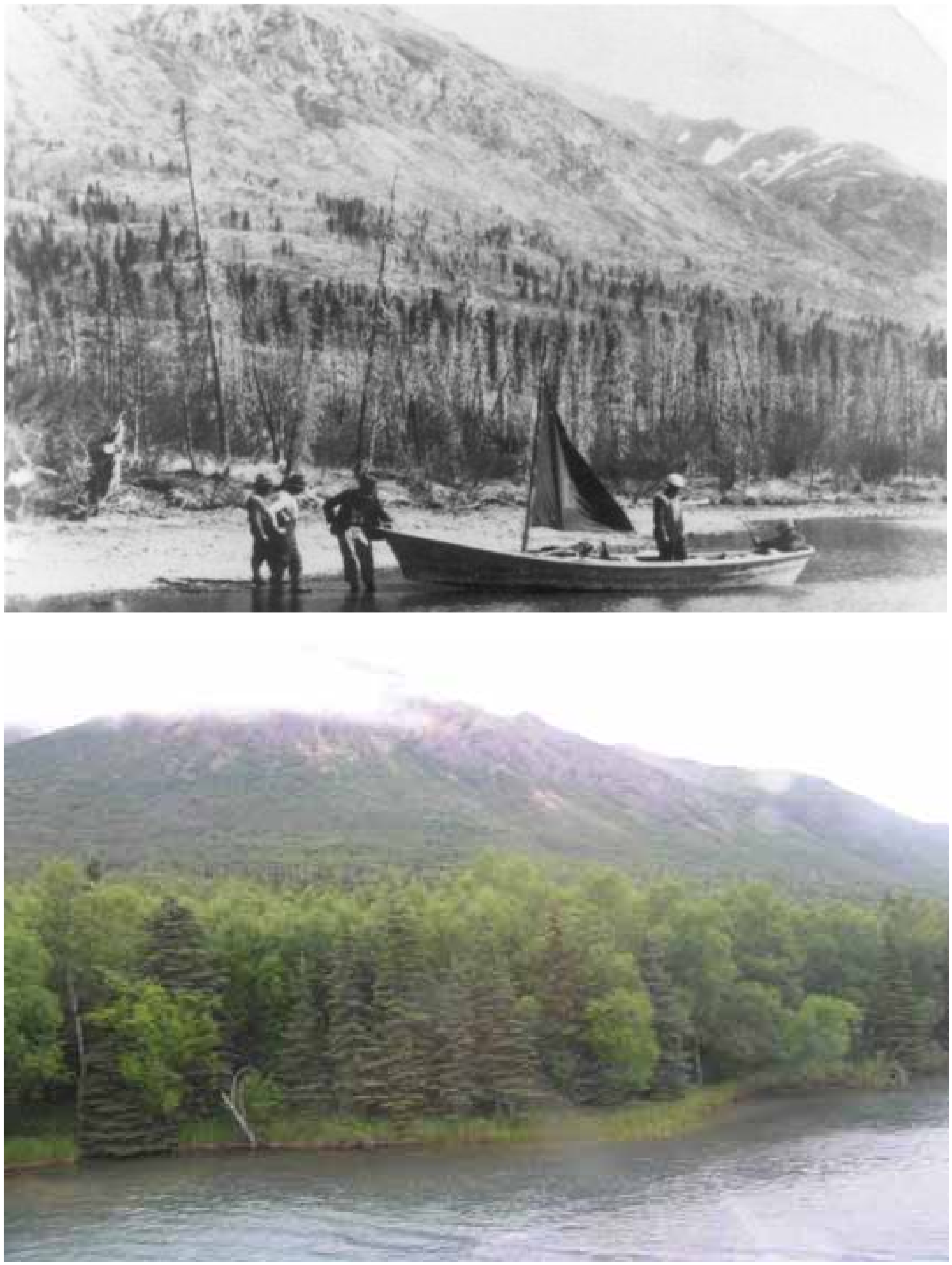

Figure 115. Shoreline of Kontrashibuna Lake in 1930 (unknown) and 2004 (M. Jorgenson). Comparison illustrates boreal forest succession after a fire that occurred not long before 1930. White spruce trees are just beginning to overtop the dense canopy formed by paper birches (*Betula papyrifera*) which are about 75 years old. 1930 photo courtesy Helena Moses.

Figure 116. Looking east toward Kenibuna Lake from ridge south of Another River in 1928 (S. Capps) and 2004 (M. Jorgenson). The Shamrock Glacier has receded ~2 km from its 1928 position near its terminal moraine. Some newly exposed morainal surfaces are now vegetated. White spruce trees and tall shrubs are larger and more numerous in the foreground at this 703 m site. 1928 photo courtesy USGS.

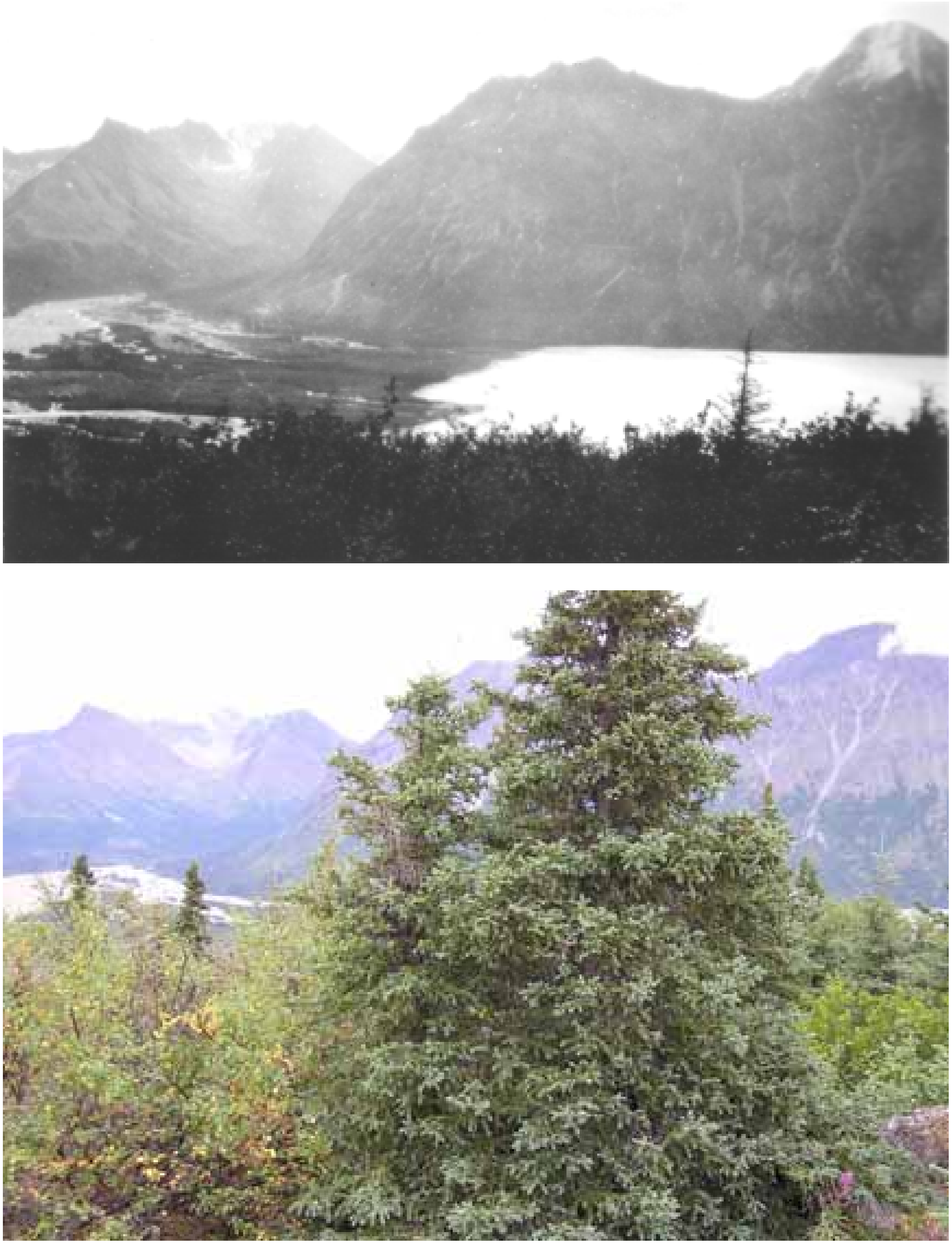

Figure 117. Panoramic view of the Two Lakes area from the west at an elevation of 710 m in 1928 (S. Capps) and 2004 (M. Jorgenson). The expansion of white spruce and paper birch trees largely obscures the former view of the Necons River mouth and the upper lake. The presence of spruce trees in 1928 indicates that the new trees probably do not reflect succession after fire. 1928 photo courtesy USGS.

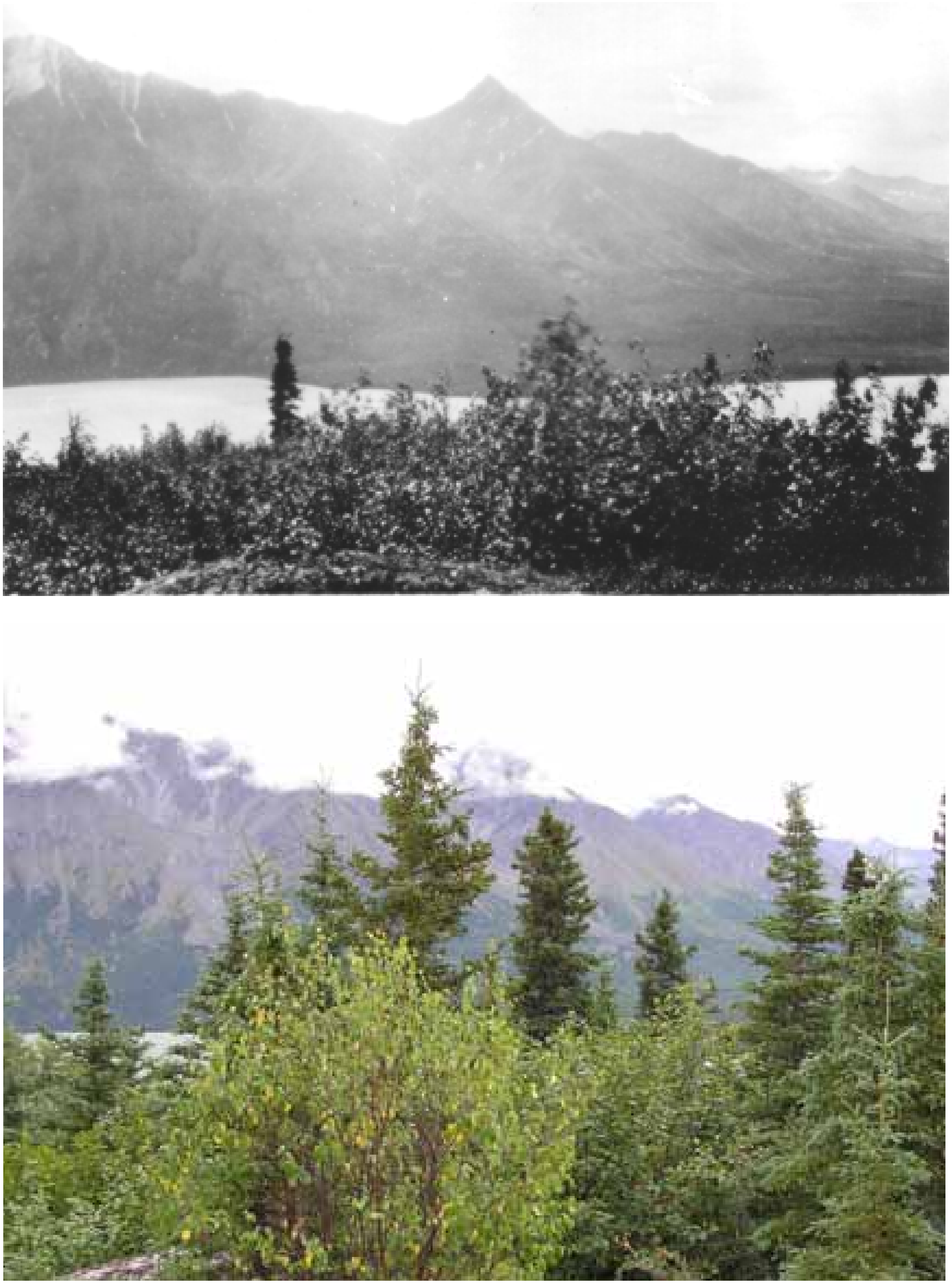

Figure 118. Continuation of panorama of the Two Lakes area in 1928 (S. Capps) and 2004 (M. Jorgenson) showing the expansion of white spruce and paper birch trees. 1928 photo courtesy USGS.

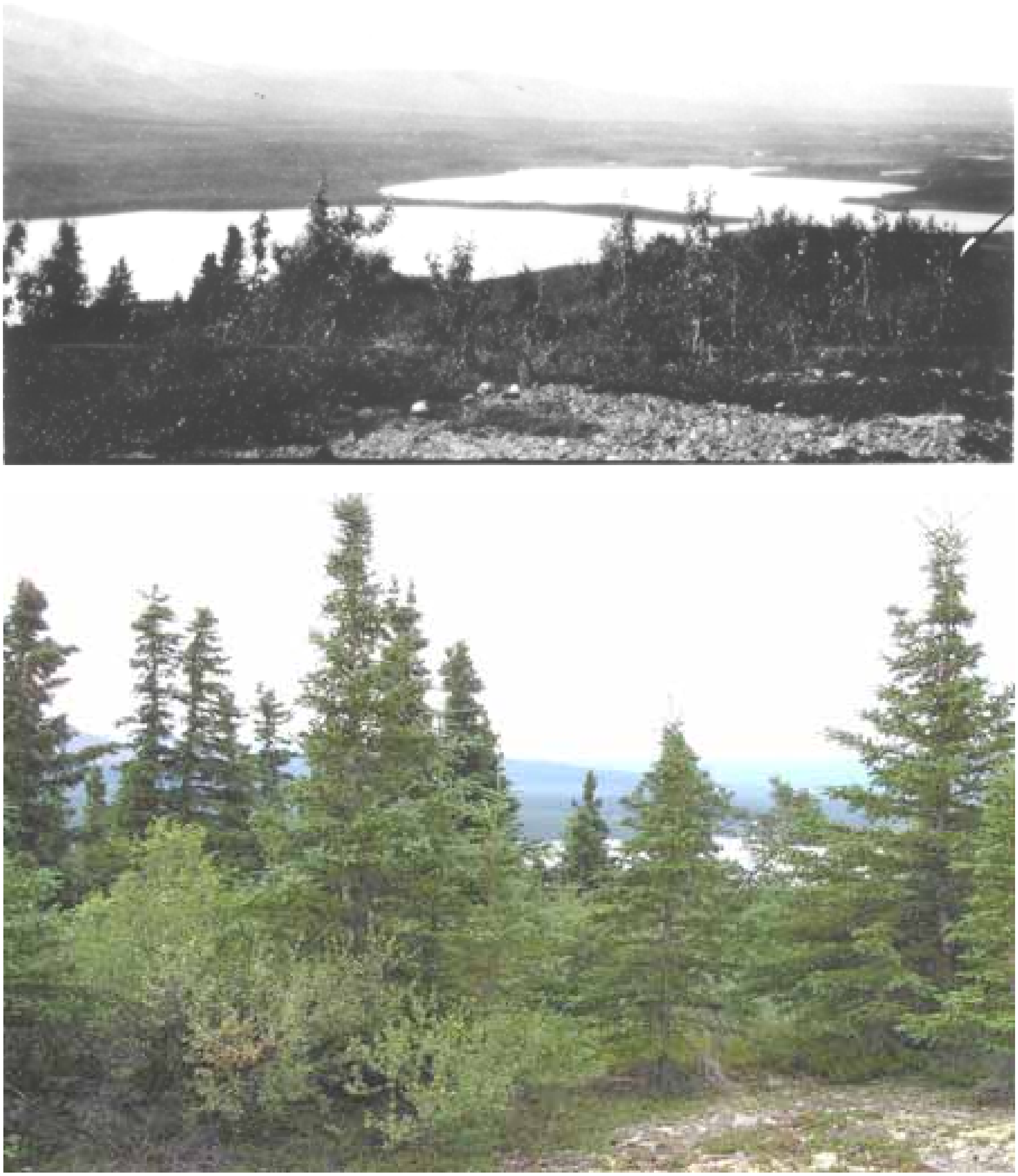

Figure 119. Continuation of panorama of the Two Lakes area in 1928 (S. Capps) and 2004 (M. Jorgenson), showing expansion of white spruce and paper birch trees. 1928 photo courtesy USGS.

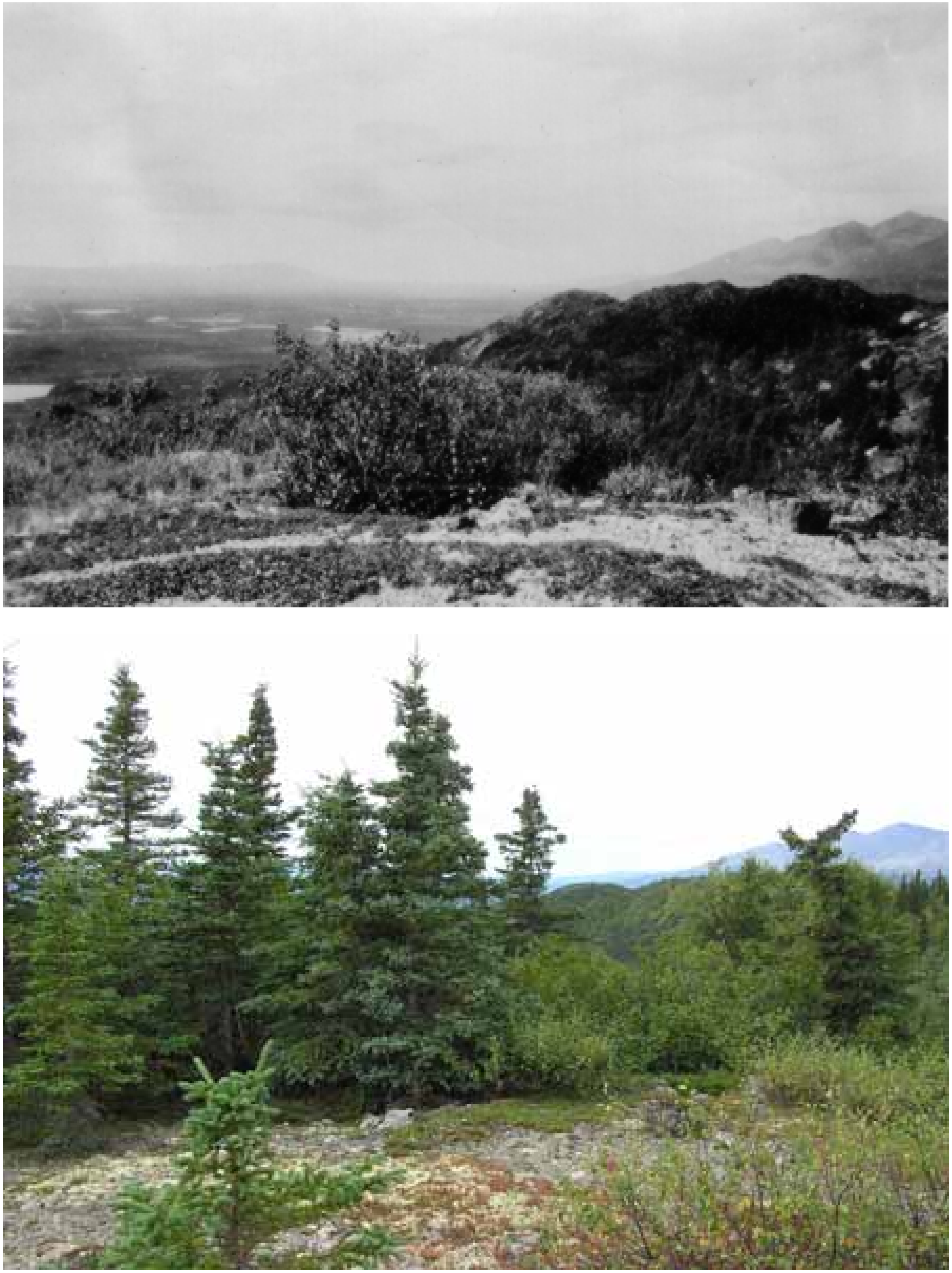

Figure 120. Continuation of panorama of the Two Lakes area in 1928 (S. Capps) and 2004 (M. Jorgenson), showing expansion of white spruce and paper birch trees. 1928 photo courtesy USGS.

Figure 121. Continuation of panorama of the Two Lakes area in 1928 (S. Capps) and 2004 (M. Jorgenson), showing the expansion of white spruce and paper birch trees. 1928 photo courtesy USGS.

Figure 122. Continuation of panorama of the Two Lakes area in 1928 (S. Capps) and 2004 (M. Jorgenson), showing the expansion of white spruce and paper birch trees. 1928 photo courtesy USGS.

Figure 123. Panorama of middle Chilligan River area in 1927 (S. Capps) and 2004 (M. Jorgenson). Expansion of white spruce and tall shrubs over a 77-year period is apparent at this 854 m site. Dominant tall shrubs at this site include resin birch (*Betula glandulosa*) and alder. Scattered balsam poplar trees are also present. 1927 photo courtesy USGS.

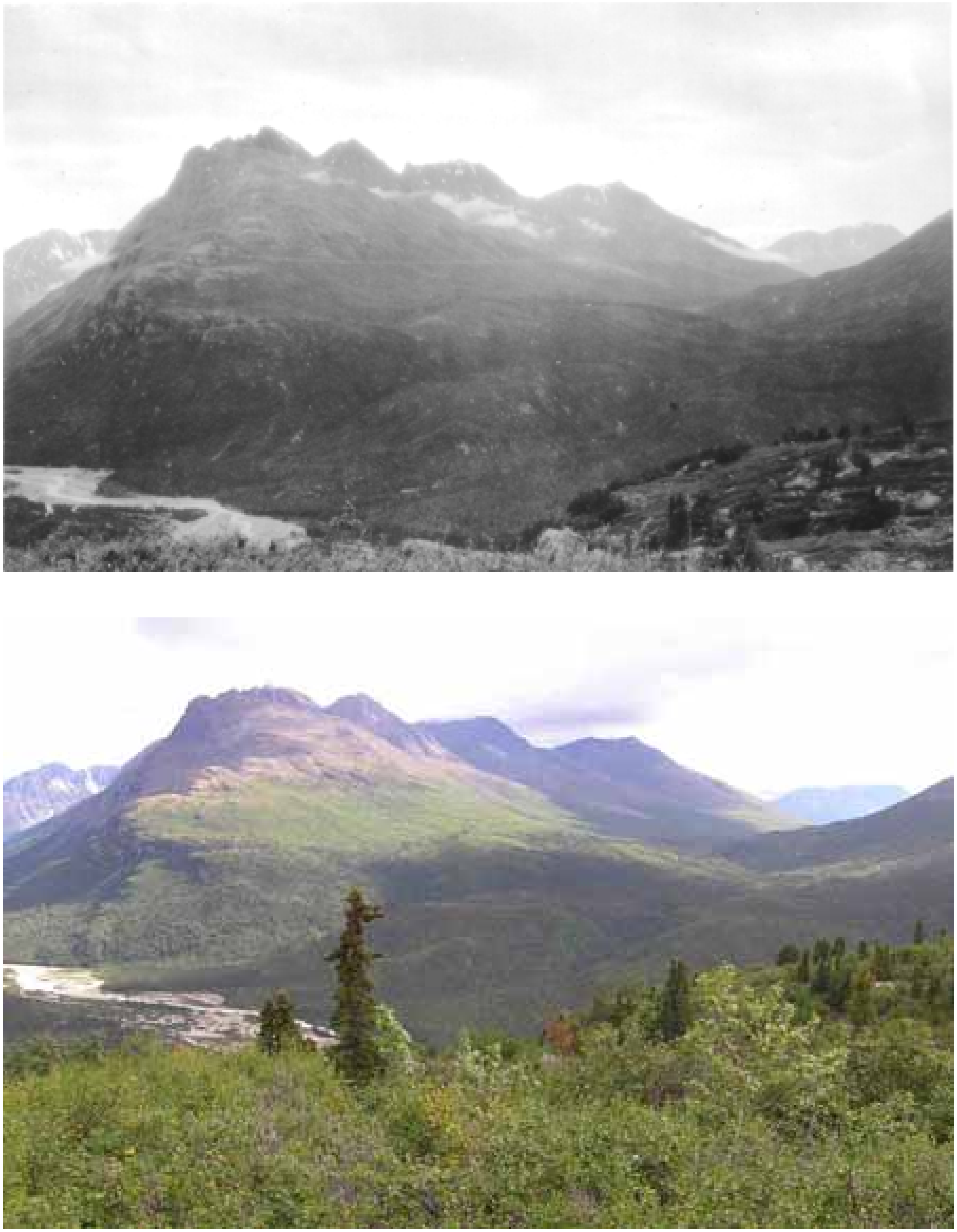

Figure 124. Continuation of panorama of the middle Chilligan River area in 1927 (S. Capps) and 2004 (M. Jorgenson). Expansion of white spruce and tall shrubs over a 77-year period is apparent at this 854 m site. Parts of the Chilligan River floodplain (lower left) have been disturbed by channel migration, while other floodplain sites that were barren in 1927 have become vegetated. 1927 photo courtesy USGS.

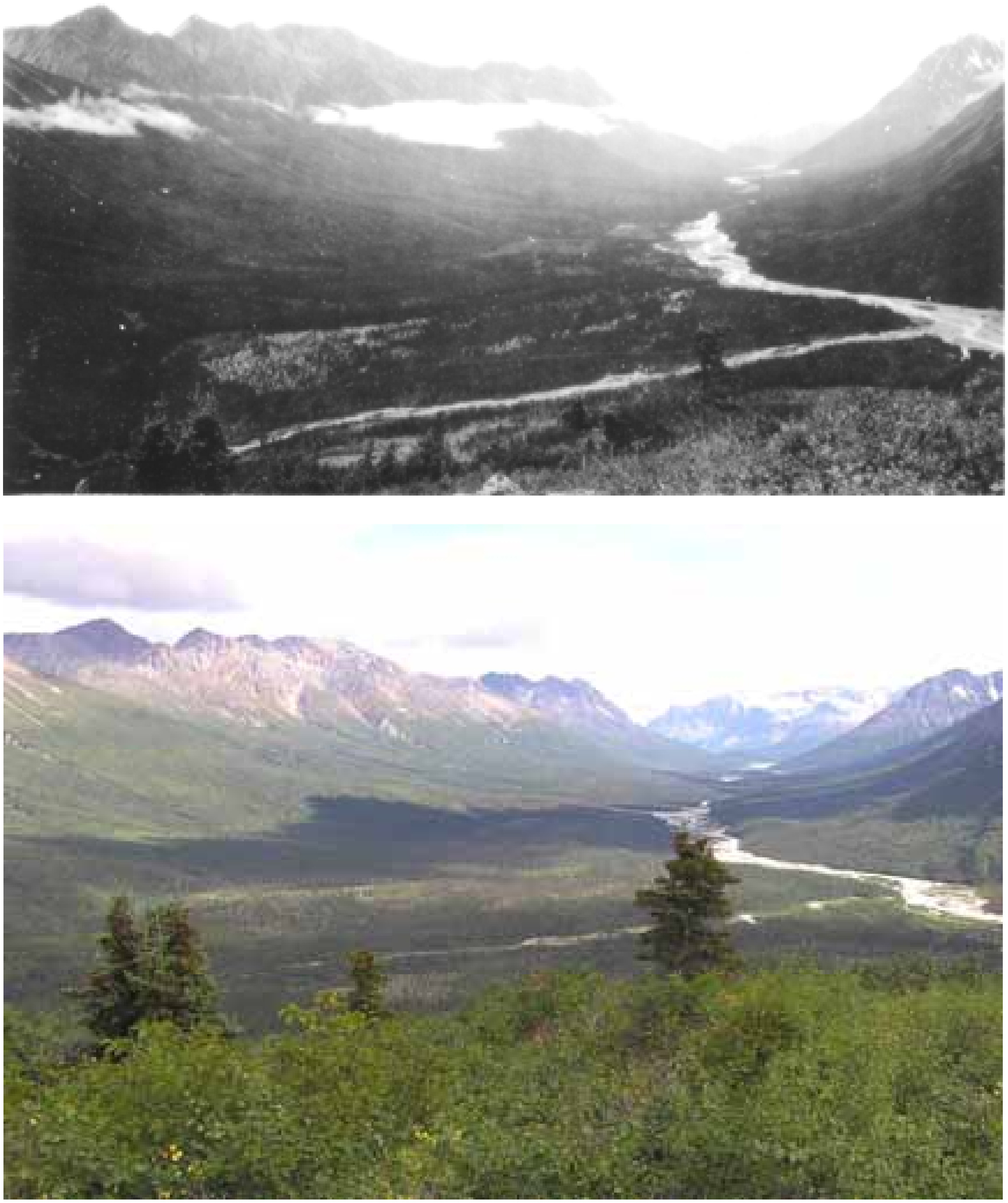

Figure 125. Continuation of panorama of the middle Chilligan River area in 1927 (S. Capps) and 2004 (M. Jorgenson) showing expansion of white spruce and tall shrubs. Channel migration and primary succession have resulted in changes on the floodplains of the Chilligan River and an unnamed tributary. 1927 photo courtesy USGS.

Figure 126. Igitna River valley in 1927 (S. Capps) and 2004 (M. Jorgenson). Comparison with Capps' 1927 image reveals little change in the mosaic of spruce woodlands, shrub thickets, and wet meadows in the valley, although spruce trees may be more numerous No expansion of trees or shrubs is apparent in the foreground at this 1,031 m site. 1927 photo courtesy USGS.

Figure 127. Looking up the valley of Another River from a mountainside in 1928 (S. Capps) and at a nearby location in 2004 (A. Bennett). Capps' image shows that spruce trees were already present in 1928 at this 762 m site, and the vegetation reflects little change since. It is not clear if any of the background mountain cirques were still glaciated in 1928. 1928 photo courtesy USGS.

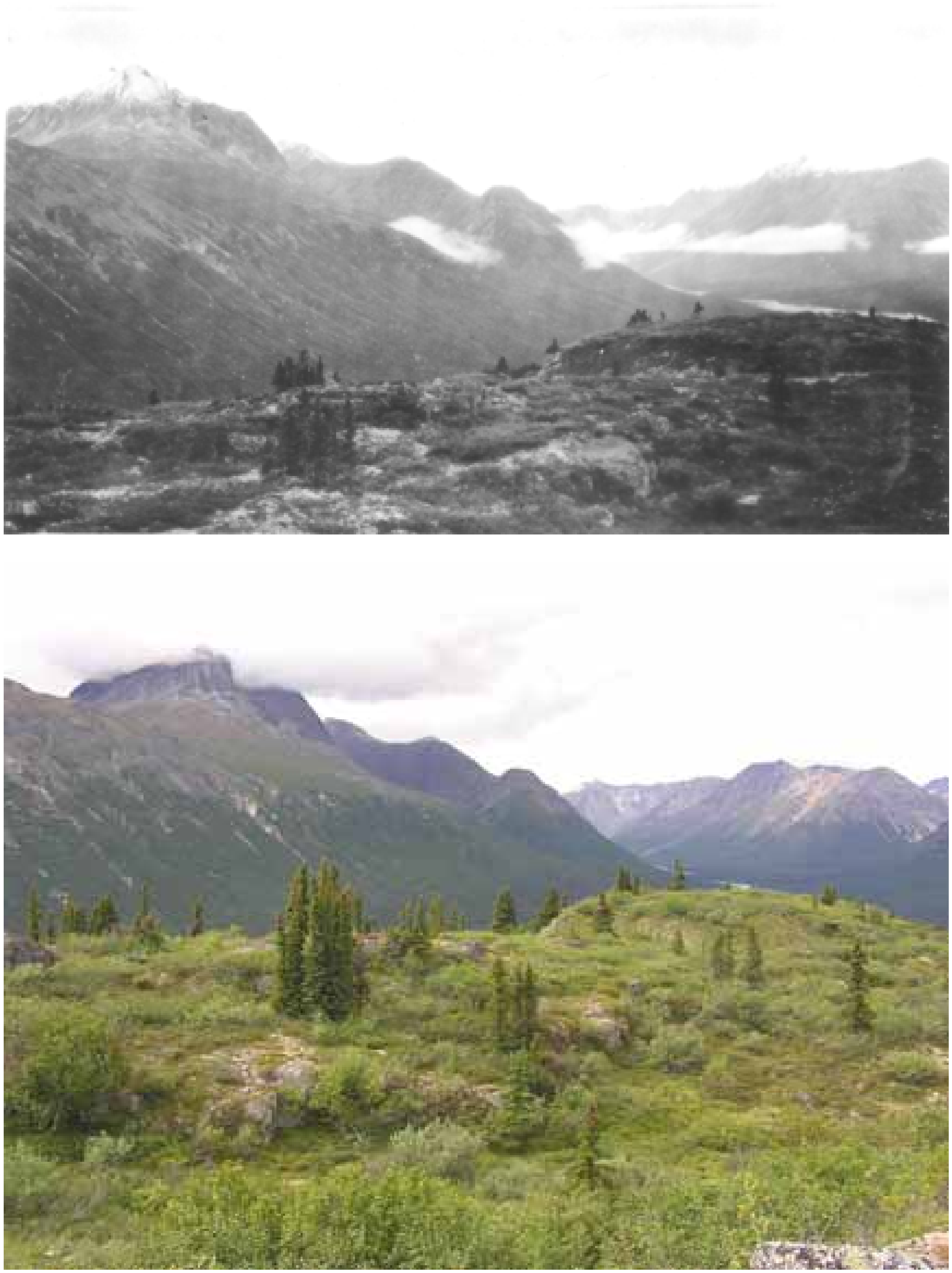

Figure 128. Panorama of middle Chilligan River valley from a summit at 854 m in 1927 (S. Capps) and 2004 (M. Jorgenson). Many of the same white spruce trees which Capps photographed are still present, but trees and tall shrubs have become larger and more numerous in the foreground. This was the highest elevation at which significant tree cover was encountered during the project. 1927 photo courtesy USGS.

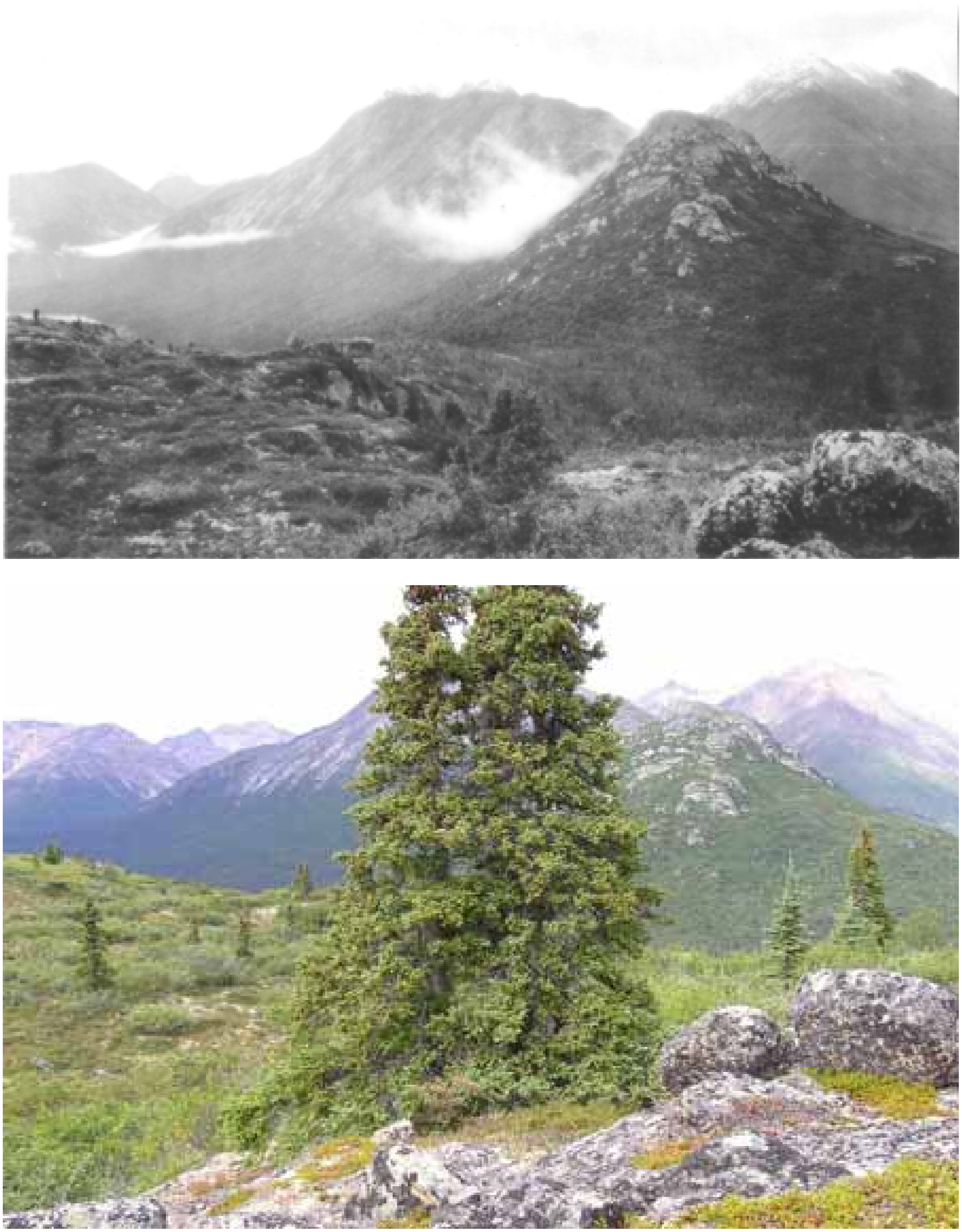

Figure 129. Continuation of panorama of middle Chilligan River area in 1927 (S. Capps) and 2004 (M. Jorgenson). White spruce trees in the 2004 view illustrate the expansion of trees and tall shrubs at this 854 m site. The lack of evidence for fire in the 1927 photo indicates that the new trees signal elevational expansion rather than recovery from fire. 1927 photo courtesy USGS.

Figure 130. Continuation of middle Chilligan River panorama in 1927 (S. Capps) and 2004 (M. Jorgenson) illustrating expansion of white spruce trees at the 854 m site. The virtually identical pattern of barren slopes in the center right background indicates that rock slides continue to renew disturbance there. 1927 photo courtesy USGS.

Figure 131. Panoramic view of middle Chilligan River valley from a summit at about 854 m in 1927 (S. Capps) and 2004 (M. Jorgenson). Several Krummholz white spruce were present in 1927, but trees and tall shrubs have become much larger and more numerous in the foreground. The expansion of spruce indicates that the site has not experienced significant disturbance for at least 77 years. 1927 photo courtesy USGS.

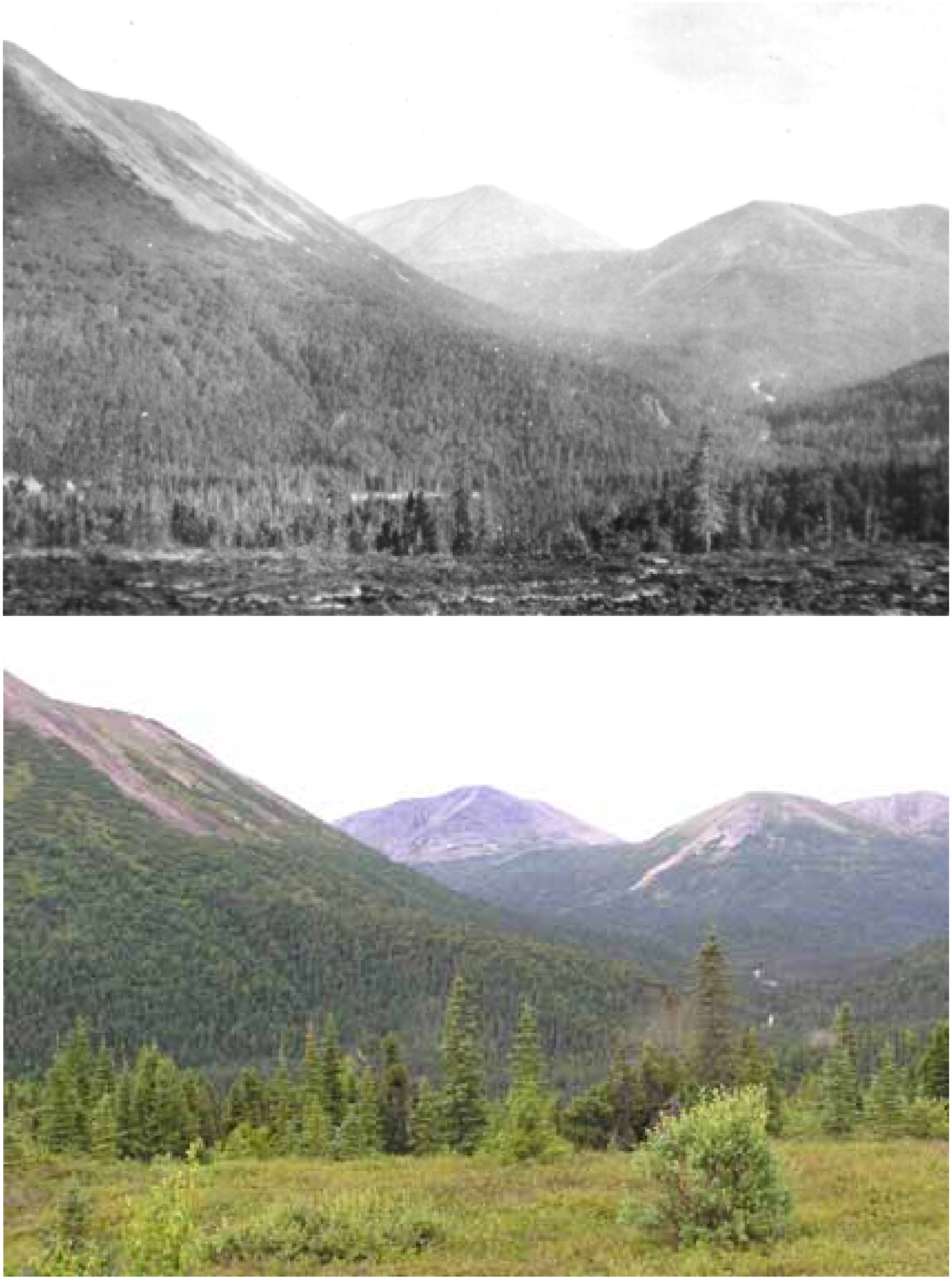

Figure 132. Photos from 1929 (S. Capps) and 2004 (M. Jorgenson) of a mountain slope showing the expansion of tall alder shrub in the subalpine zone along the Kijik River. Lower on the slope, white spruce trees have emerged from the canopy and now dominate the mixed spruce-birch forest. The elevation at the vantage point is 428 m. 1929 photo courtesy USGS.

Figure 133. Panoramic view of the middle Igitna River valley from an elevation of about 1,030 m in 1927 (S. Capps) and 2004 (M. Jorgenson). Trees and tall shrubs have not established at this elevation and there appears to be little change in the low scrub vegetation in the foreground. Tall scrub appears to be more extensive on the opposite mountainside, and the cirque glacier at center shrank. 1927 photo courtesy USGS.

Figure 134. Colluvial deposits near Merrill Pass in 1928 (S. Capps) and 2004 (A. Bennett). Virtually no changes are apparent at this alpine location since Capps visited it in 1928. At about 945 m, this site remains above treeline. 1928 photo courtesy USGS.

Figure 135. Wet coastal meadow near the head of Chinitna Bay in 1948 (D. Miller) and 2004 (M. Jorgenson). Comparison shows the persistence of an herbaceous plant community at this site that probably experienced seismic uplift following the 1964 earthquake. A spruce forest has remained undisturbed on the hillside at left over the 56 year interval. 1948 photo courtesy USGS.

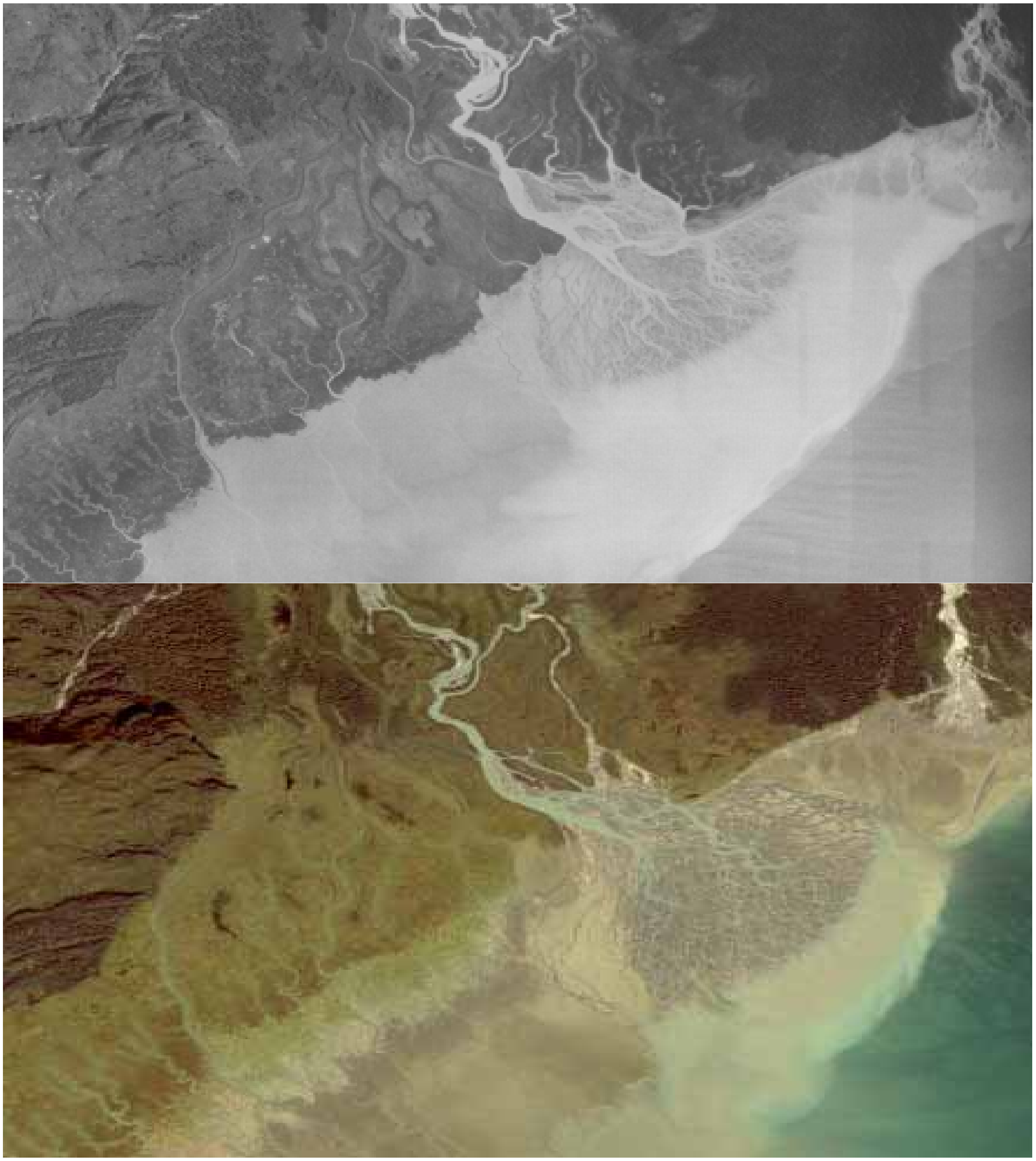

Figure 136. Effects of coastal uplift from the 1964 earthquake are evident near the mouth of Middle Glacier Creek from a 1954 airphoto and an Ikonos image from 2004. Comparison reveals extensive development of salt meadows on the mudflats. On the higher, inactive mudflats, many of the tidal ponds have drained by 2004. Little change is evident in the dendritic network of tidal guts on the inactive flats.

Figure 137. Fossil Point in Tuxedni Bay seen at low tide in 1895 (C. Purington) and from the air near high tide in 2004 (M. Jorgenson). Photo comparison reveals little change in the bedrock coastline and the persistence of alder shrub vegetation along the cliff. 1895 photo courtesy USGS.

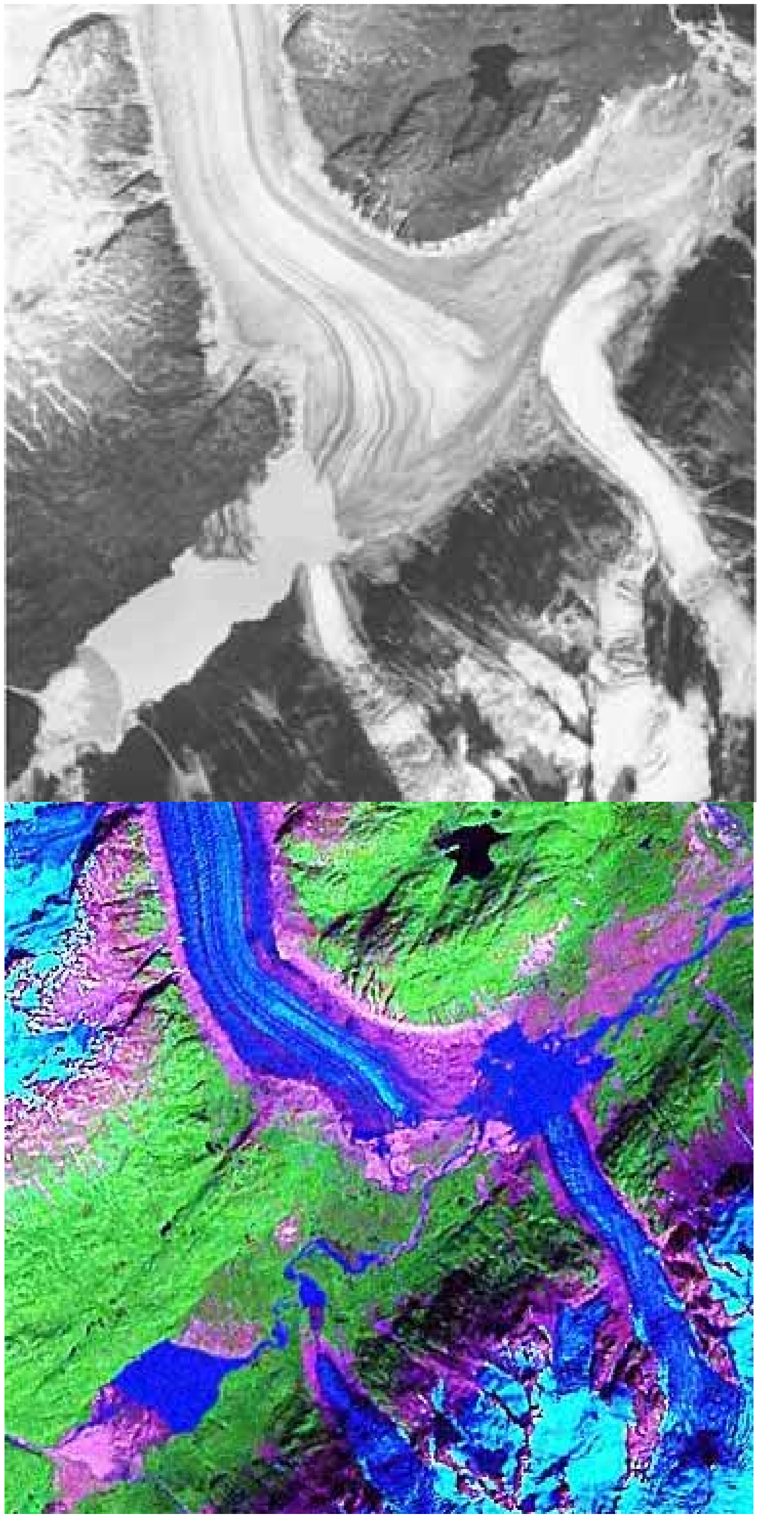

Figure 138. Comparison of an aerial photograph from 1954 and a Landsat image from 1999 reveals that the Tanaina Glacier has retreated ~1.4 km over a 59-year period. Other aerial photographs from 1973 and 1979 show that most of the retreat occurred between 1954 and 1979, with only minor retreat from 1979 to 1999, although the early faster retreat was probably related to the thinner ice at the glacier margin.

Figure 139. Looking southeast over Surprise Lake from knoll between coves in 1930 (B. Hubbard) and 2006 (G. Frost). Comparison indicates that current foreground vegetation cover exceeds that preceding the1931 eruption. Partially vegetated barrens in the foreground grade into crowberry dwarf scrub and low open willow in the gully at left. The shoreline of Surprise Lake has been modified by alluvial deposition, and the water level appears to be higher. 1930 photo courtesy Santa Clara University.

Figure 140. Cove on southwestern shore of Surprise Lake in 1930 (B. Hubbard) and 2005 (T. Jones). Comparison indicates that vegetation is more extensive at the site today than it was before the 1931 eruption. In particular, willows (primarily *Salix alaxensis* and *S. barclayi*) are much more abundant. 1930 photo courtesy Santa Clara University. 1930 photo courtesy Santa Clara University.

Figure 141. Surprise Lake cove seen in Figure 140 in 1931 (B. Hubbard) and 2005 (T. Jones). Vegetation recovery has advanced relatively quickly in the gully after tephra burial in 1931. Willows and forbs such as Nootka lupine (*Lupinus nootkatensis*) form the dominant ground cover. 1931 photo courtesy Santa Clara University.

Figure 142. Easternmost cove on the south side of Surprise Lake in 1973 (K. Trexler) and 2006 (G. Frost). Since 1973, willows have increased in coverage and height.

Figure 143. Low slope above traditional camp cove at Surprise Lake seen in 1972 (K. Trexler) and 2006 (G. Frost). Comparison reveals the persistence of arctic willow (*Salix arctica*) on exposed sites in the area. Extensive dead branches in 1972 suggest that these long-lived dwarf shrubs were severely damaged by the 1931 eruption, but substantially recovered by 1972. Since then they showed little change. Cover of moss (*Racomitrium* sp.) has increased markedly, although total live cover at the site remains <50%.

Figure 144. Cove on southwestern shore of Surprise Lake in 1973 (P. Vaughn) and 2005 (T. Jones). Feltleaf willows have established in the beach ryegrass meadow in the foreground. Slumped material has become vegetated at the base of the knoll in the background, but vegetation expansion is less apparent on the knoll top.

Figure 145. Cove on southwestern shore of Surprise Lake in 1976 (D. Follows) and 2005 (T. Jones). Feltleaf willows have expanded markedly at the base of the knoll, but vegetation expansion is less apparent on the knoll top.

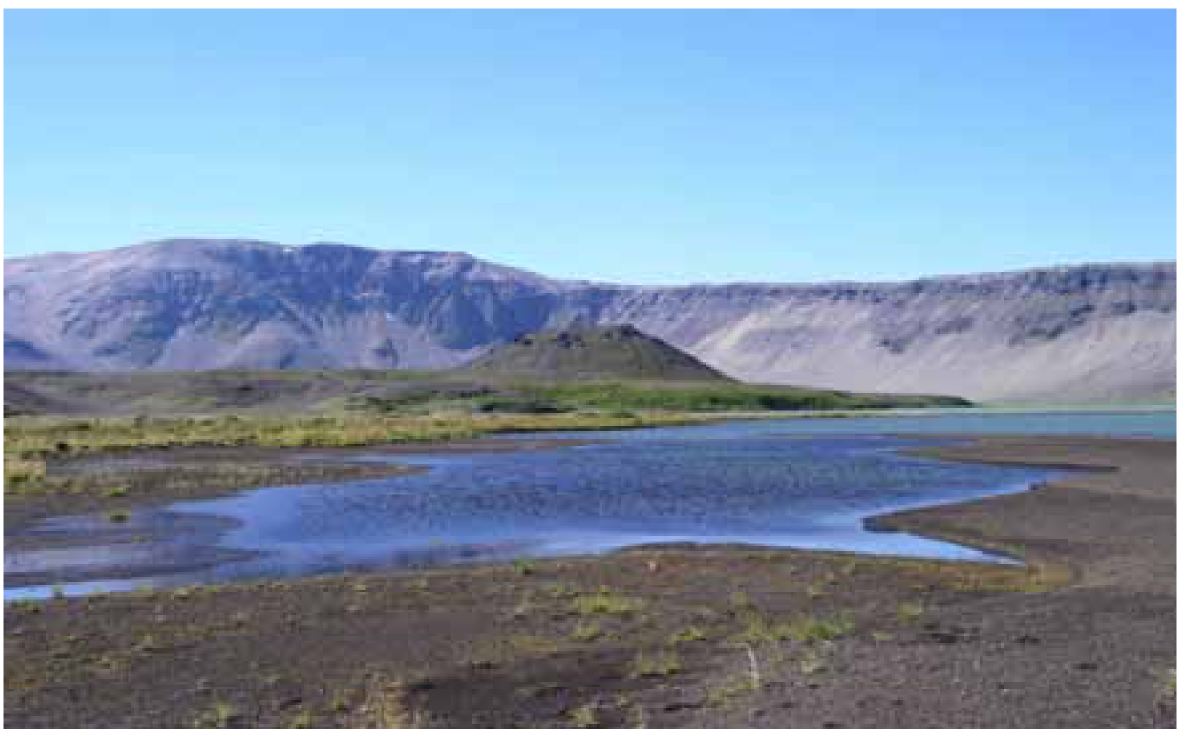

Figure 146. Looking northwest along the south shore of Surprise Lake in 1930 (B. Hubbard) and 2005 (T. Jones). Graminoid-dominated vegetation along the current shoreline appears structurally similar to shoreline vegetation present before the 1931 eruption. The lake level appears to be higher today, even relatively late in the summer when most seasonal snow has melted. 1930 photo courtesy Santa Clara University.

Figure 147. Northwest shore of Surprise Lake in 1930 (B. Hubbard) and 2005 (T. Jones). Vegetation recovery is at an advanced stage along the lake shoreline. The current cover of graminoids and forbs appears similar to vegetation preceding the 1931 eruption. Some shoreline erosion is evident at left. 1930 photo courtesy Santa Clara University.

Figure 148. Looking toward Vent Mountain from the southwest shore of Surprise Lake in 1930 (B. Hubbard) and from the same approximate location in 2006 (G. Frost). Most of the sparse foreground vegetation in the 1930 image appears to be beach ryegrass. The current cover of low willows, forbs, and graminoids indicates that vegetation recovery has been relatively rapid near the lake, but very slow in the background. 1930 photo courtesy Santa Clara University.

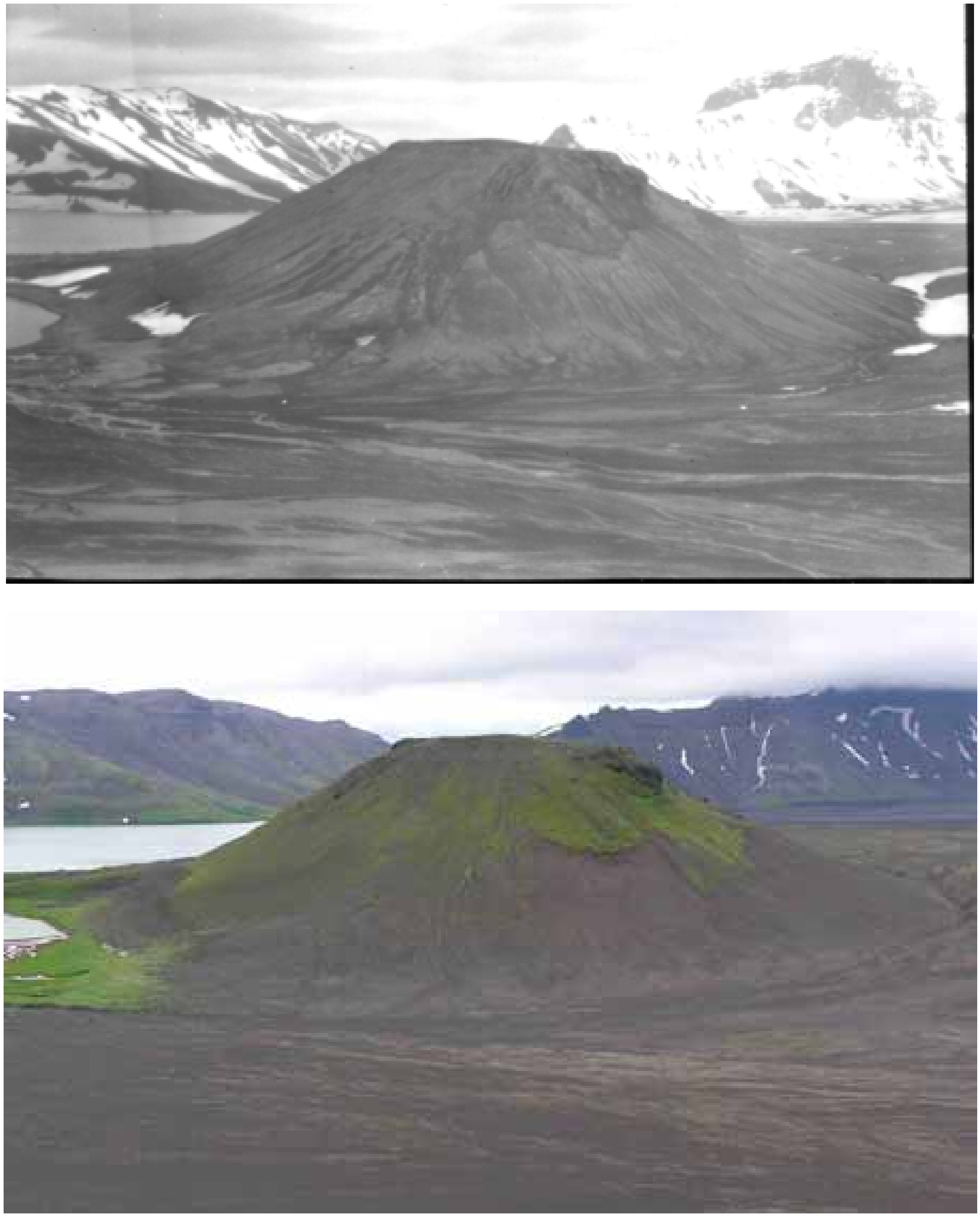

Figure 149. “Bolshoi Dome” seen from “Vulcan Dome” in 1930 (B. Hubbard) and 2004 (A. Miller). It is difficult to assess vegetation cover using Hubbard’s black & white image. Since the eruption, virtually no vegetation has established on tephra in the foreground, but vegetation recovery is apparent near the lake. 1930 photo courtesy Santa Clara University.

Figure 150. Looking toward Vent Mountain from alluvial flats in Aniakchak Caldera near The Gates in 1931 (B. Hubbard) and 2006 (D. Mortenson). Vegetation recovery after tephra burial in 1931 is dramatically illustrated in the foreground by low open willow scrub with a diverse herbaceous understory. This area is laced with several spring-fed creeks. Exposed cinder fields in the background remain barren. 1931 photo courtesy Santa Clara University.

Figure 151. Alluvial flats near the northwest end of Surprise Lake in 1972 (K. Trexler) and 2006 (G. Frost). Beach ryegrass has colonized surfaces that were still barren in 1972, and forbs such as Nootka lupine, seacoast angelica, and northern yarrow (*Achillea borealis*) are now codominant on the older ryegrass meadows.

Figure 152. Northwestern shoreline of Surprise Lake in 1972 (B. Moorehead) and 2005 (T. Jones). In the foreground, a diverse mesic herb community has established in what was a nearly pure beach ryegrass meadow in 1973. Important new species include Nootka lupine, seacoast angelica, and northern yarrow.

Figure 153. Source of warm springs at base of “Bolshoi Dome” in 1972 (K. Trexler) and 2005 (T. Jones). The distribution of vegetation lining the springs has changed somewhat, but is still primarily composed of Lyngbye’s sedge.

Figure 154. Warm springs entering northwestern end of Surprise Lake in 1972 (B. Moorehead) and 2005 (T. Jones). Lyngbye's sedge continues to line the stream, while alluvial flats in the background now support scattered grasses, primarily Bering's tufted hairgrass (*Deschampsia beringensis*).

Figure 155. Warm springs at northwest end of Surprise Lake seen in 1974 (E. Stondall) and in 2004 (A. Miller). Foreground vegetation 1974 was strongly dominated by beach ryegrass, but forbs have become codominant. Beach ryegrass has expanded on the alluvial flats near the lake and on the slopes behind.

Figure 156. Northwest end of Surprise Lake seen from summit of "Bolshoi Dome" in 1973 (K. Trexler) and 2006 (G. Frost). Comparison reveals modest increase in cover of prostrate vegetation on the exposed foreground slope, while vegetation expansion is conspicuous on the alluvial flats and adjacent lower slopes in the background. Alluvial deposition continues to modify the lake shoreline at the creek mouth.

Figure 157. Looking down the Aniakchak River valley ~1 km below The Gates in 1931 (B. Hubbard) and 2006 (G. Frost). Tephra covered everything in the 1931 image. By 2006, a mesic forb meadow with scattered low willows has established in the foreground, although some surfaces remain barren. Dominant species include Nootka lupine and seacoast angelica. 1931 photo courtesy Santa Clara University.

Figure 158. Looking toward The Gates ~1 km outside the Aniakchak Caldera in 1931 (B. Hubbard) and 2006 (G. Frost). Tephra covered everything in the 1931 image. A mesic forb meadow with scattered low willows has developed on the river floodplain. Some steep slopes in the right background have also become vegetated. 1931 photo courtesy Santa Clara University.

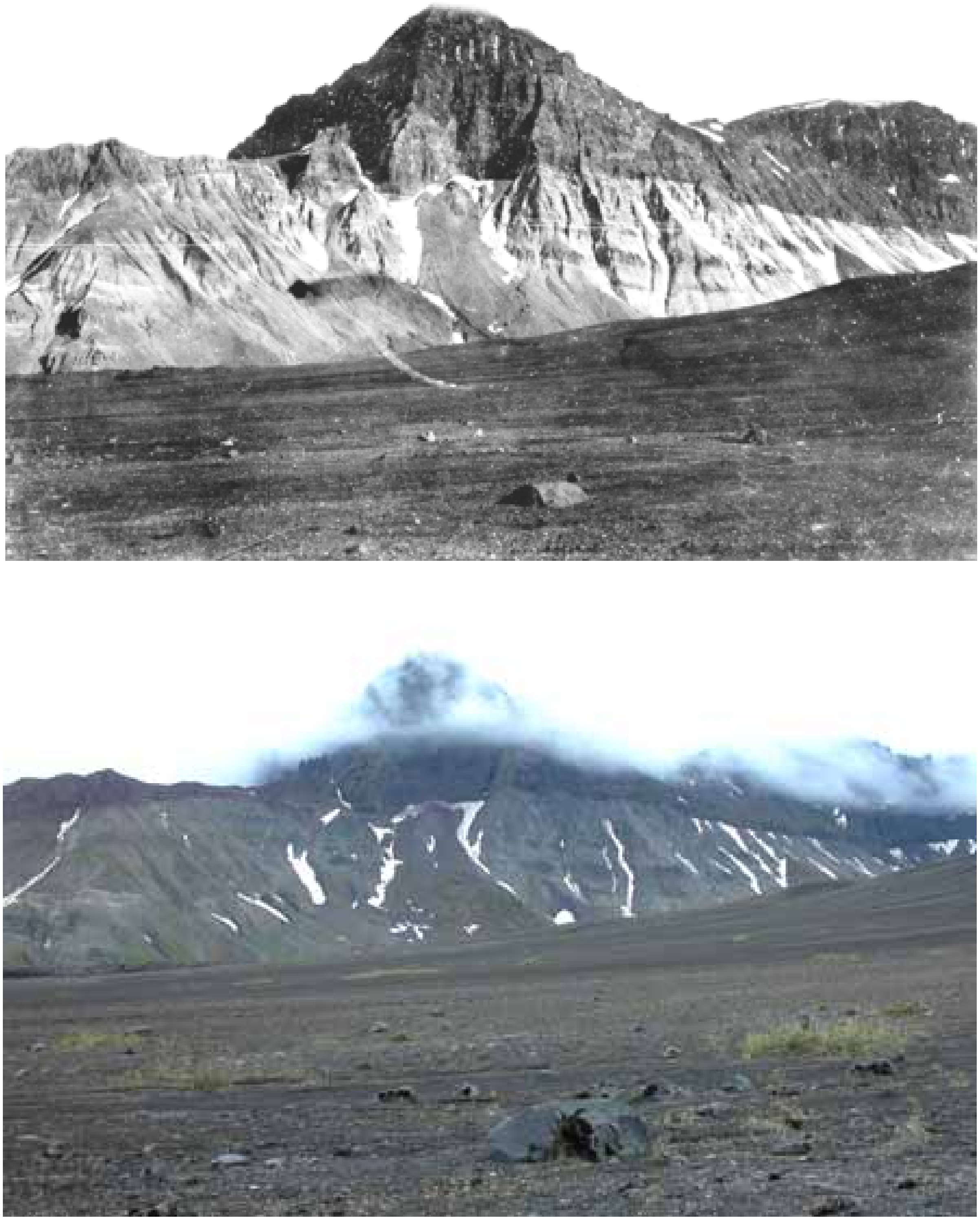

Figure 159. Black Nose seen from cinder fields inside Aniakchak Caldera in 1922 (W. Smith) and 2006 (G. Frost). The 1922 photo, among the oldest in the collection for Aniakchak, indicates that the foreground area was largely barren even before the 1931 eruption. Beach ryegrass composes most of the sparse vegetation present in 2006. Large colluvial boulders below the summit of Black Nose indicate recent landslide activity. 1922 photo courtesy USGS.

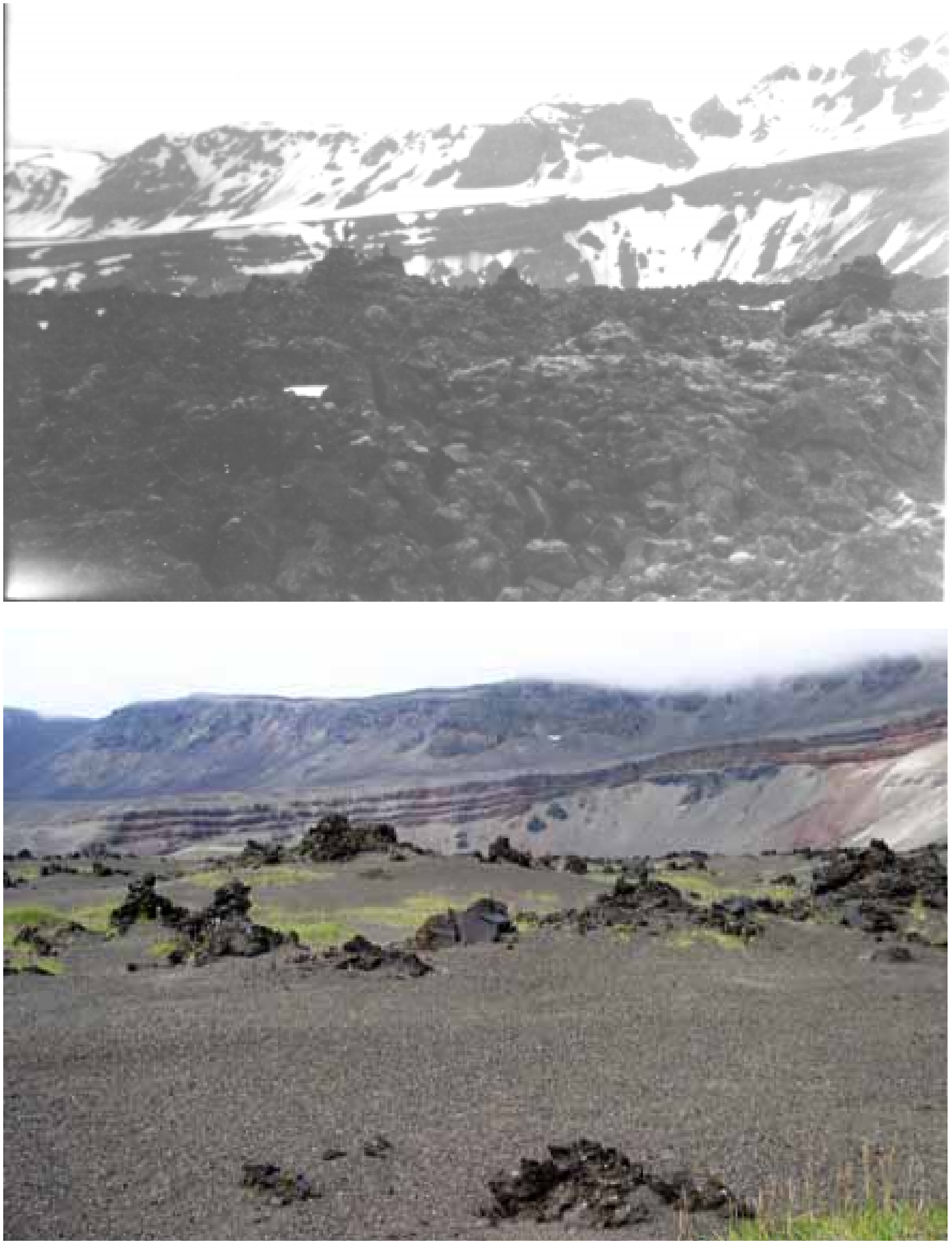

Figure 160. Half Cone lava field in 1930 (B. Hubbard) and 2005 (T. Jones). Most of the lava field was buried by coarse tephra in 1931. Beach ryegrass has begun to colonize the tephra. Common on 1931 lava rocks, the lichen *Stereocaulon vesuvianum* is virtually absent from these older lavas. 1930 photo courtesy Santa Clara University.

Figure 161. Looking towards Vent Mountain from the southern shoreline of Surprise Lake in 1976 (D. Follows) and 2006 (G. Frost). Comparison reveals the persistence of beach ryegrass on alluvial cinder flats, although little expansion over the 30-year interval is evident at this site.

Figure 162. “Vulcan Dome” and “Bolshoi Dome” from uplands northeast of Half Cone in 1976 (M. Malik) and the same approximate location 2006 (G. Frost). The prevalent colonist in the northern portion of Aniakchak Caldera, beach ryegrass has expanded significantly in this area over the 30-year interval.

Figure 163. Lava and ash field east of Half Cone in 1972 (K. Trexler) and 2005 (T. Jones). Primary succssion is occurring slowly on the coarse tephra and only scattered tillers of beach ryegrass have appeared over the 33-year interval.

Figure 164. Uplands south of Surprise Lake seen from summit of “Bolshoi Dome” in 1973 (K. Trexler) and from the same approximate location in 2006 (G. Frost). Expansion of vegetation is evident along the low ridges in the foreground. Beach ryegrass is the principle colonizing species, while sites that were already vegetated in 1973 tend to be codominated by forbs.

Figure 165. Primary 1931 crater and lava dome in 1931 (B. Hubbard) and 2005 (T. Jones). The lava appears white due to profuse cover of the fruticose lichen *Stereocaulon vesuvianum*. Although overall vascular plant cover is low on the lava, diversity is high. Primary succession has occurred much more slowly on extensive tephra deposits outside of the 1931 crater. 1931 photo courtesy Santa Clara University.

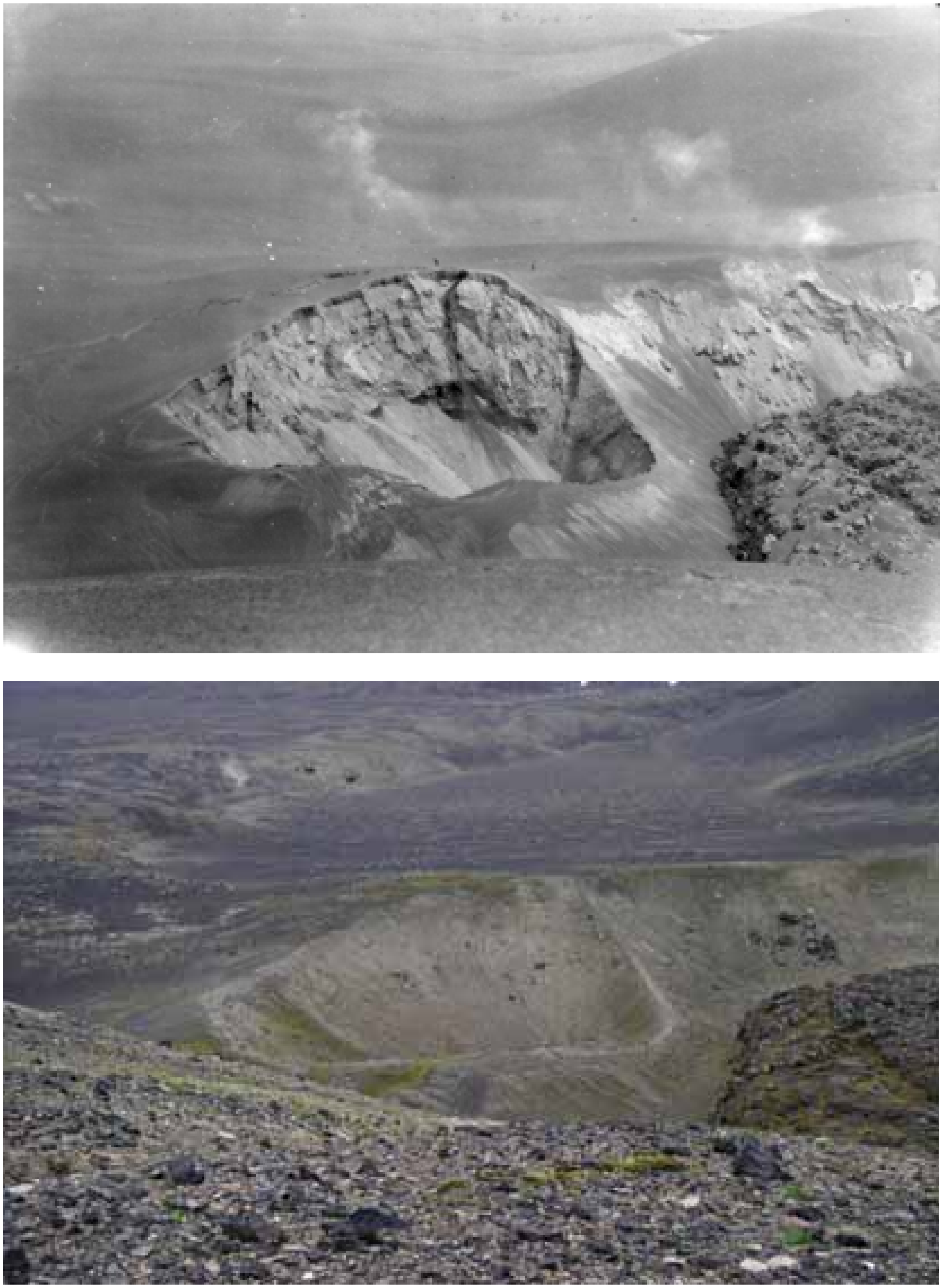

Figure 166. Collapse pit on rim of lava dome near Birthday Pass in 1931 (B. Hubbard) and 2005 (T. Jones). Primary succession has proceeded at a slow pace at this site, which was a secondary center of 1931 volcanism. New vegetation is most conspicuous on the lava dome itself (right). Piper’s woodrush is the most common vascular plant in this portion of Aniakchak Caldera. 1931 photo courtesy Santa Clara University.


Figure 167. Lava rocks at “Slag Heap” near Birthday Pass in 1931 (B. Hubbard) and 2005 (T. Jones). Plant colonization has occurred slowly in this part of Aniakchak Crater, although these tephra-mantled 1931 lavas now support sparse plant cover. Vegetation is primarily Piper’s woodrush and the fruticose lichen *Stereocaulon vesuvianum*. 1931 photo courtesy Santa Clara University.

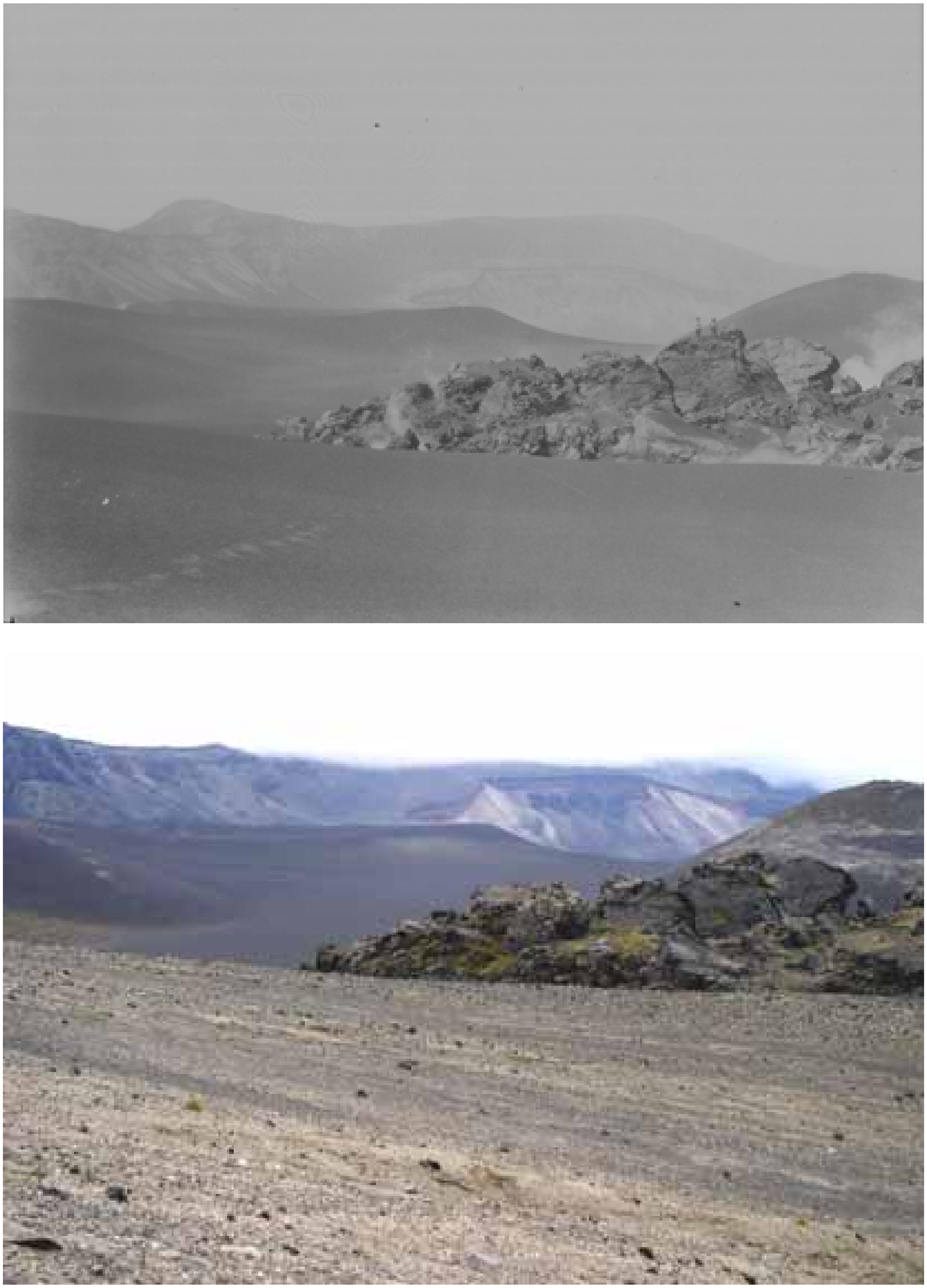

Figure 168. Tephra-mantled lava rocks at “Slag Heap” near Birthday Pass in 1931 (B. Hubbard) and 2005 (T. Jones). Primary succession is occurring at a very slow pace in the area. Plant cover is conspicuous only within the microenvironment of the lava rocks and on a toe slope in the left background. 1931 photo courtesy Santa Clara University.

Figure 169. “Slag Heap” near Birthday Pass in 1931 (B. Hubbard) and 2005 (T. Jones). Primary succession is occurring at a very slow pace in the area and plant cover is conspicuous only in sheltered microsites such as the small gullies on the slope. 1931 photo courtesy Santa Clara University.

Figure 170. Secondary 1931 lava dome near Birthday Pass in 1972 (K. Trexler) and 2006 (G. Frost). Following 1931 volcanism, this site remains largely barren and visible increase in cover of vascular plants (primarily Piper's woodrush) has been modest over the 34-year interval. The conspicuous white fruticose lichen *Stereocaulon vesuvianum* persists on the young lava rocks.

Figure 171. Looking north over 1931 lava dome near Birthday Pass in 1976 (D. Follows) and 2006 (G. Frost). A secondary center of volcanic activity in 1931, plant colonization in the area has been slow and increases in vegetation cover have been modest over the last 30 years.

Figure 172. Half Cone area seen from east in 1976 (D. Follows) and 2006 (G. Frost). A modest increase in plant cover is apparent in the foreground at this exposed site. Although plant cover is sparse, diversity is relatively high compared to the ryegrass-dominated cinder fields prevalent in the northern portion of Aniakchak Caldera.

Figure 173. Cinder field in southwestern Aniakchak Caldera in 1976 (D. Follows) and 2004 (A. Miller). Primary succession is occurring at a slow pace in the area. Vegetation in the foreground of the 2004 photo is predominantly composed of Piper’s woodrush and mosses. Beach ryegrass, an important colonizer in the northern portion of the caldera, is absent in this area.

Figure 174. Southeast side of “Surprise Cone” north of Vent Mountain seen in 1931 (B. Hubbard) and 2005 (T. Jones). The extensive cover of arctic willow and Kamchatka rhododendron (*Rhododendron camschaticum*) is unusual on this exposed slope. These slow-growing dwarf shrubs may represent holdover vegetation that survived where 1931 tephra did not persist. 1931 photo courtesy Santa Clara University.

Figure 175. Looking toward Half Cone from "Surprise Cone" in 1930 (B. Hubbard) and 2005 (T. Jones). Primary succession is occurring relatively quickly in gully snowbed sites, while exposed sites remain largely barren. Dominant species include beach ryegrass, seacoast angelica, and Nootka lupine. 1930 photo courtesy Santa Clara University.

Figure 176. Upper Aniakchak River area ~6 km below The Gates in 1973 (K. Trexler) and 2006 (G. Frost). In only 33 years, alder shrubs have expanded markedly, obscuring the lower river terrace at right. Some of the shrub expansion may reflect vegetation recovery after the 1931 eruption.

Figure 177. Upper Aniakchak River ~6 km below The Gates in 1973 (K. Trexler) and 2006 (G. Frost). In only 33 years, alder and willow have expanded markedly. Some of the shrub expansion may reflect vegetation recovery after the 1931 eruption.

Figure 178. Upper Aniakchak River seen from cutbank edge ~6 km below The Gates in 1973 (K. Trexler) and 2006 (G. Frost). On the background slope, tall shrubs appear to have encroached into meadows since 1973. On the floodplain, a 1973 gravel bar has been vegetated by willows and the channel has shifted towards the foreground.

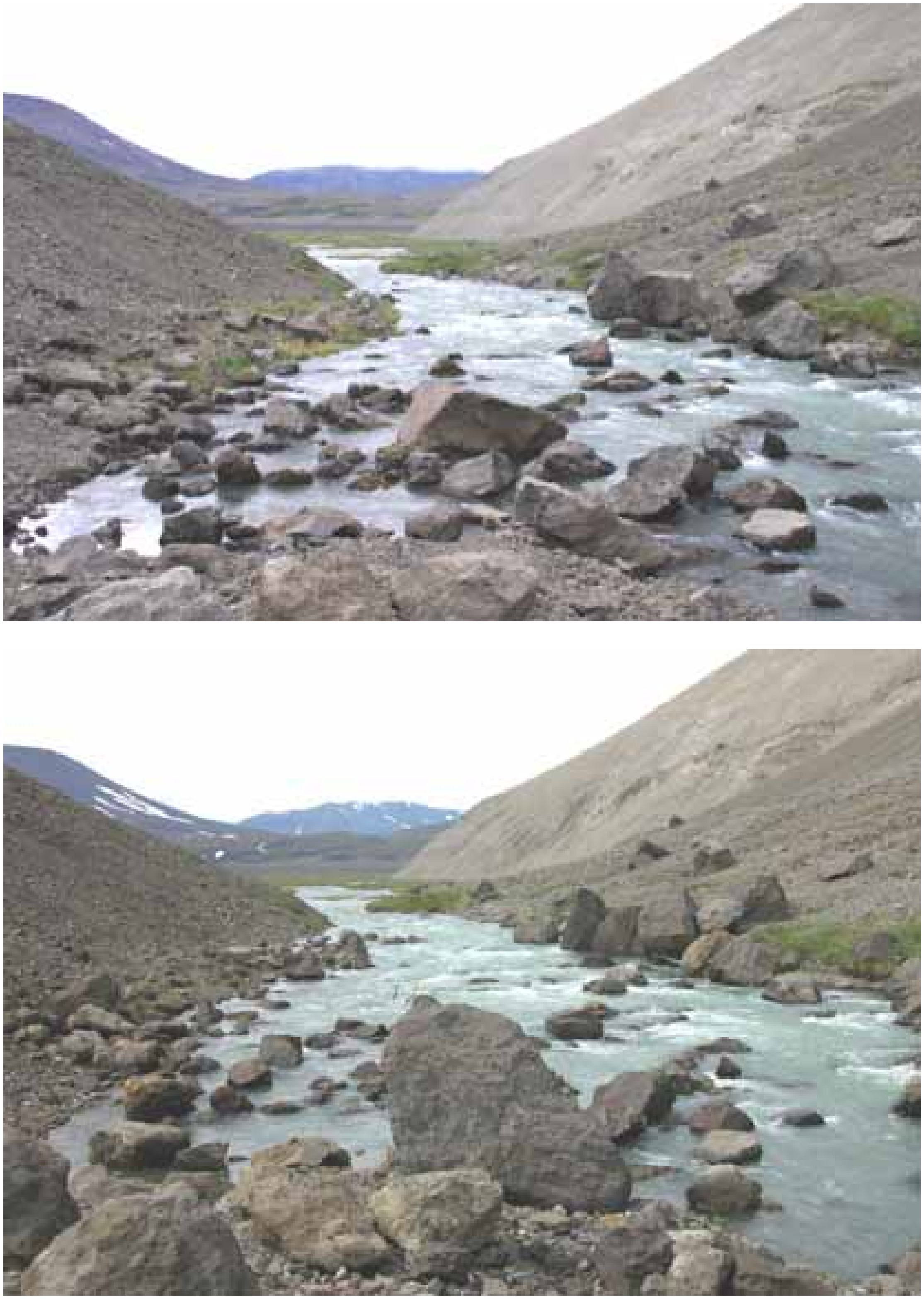

Figure 179. Looking up the Aniakchak River in The Gates in 2005 (T. Jones) and 2006 (G. Frost). Most of the large colluvial boulders were deposited after an earthquake in 2005, but the appearance of several new boulders by July 2006 indicates ongoing landslide activity on the northern slopes of Black Nose.

Figure 180. Upper Aniakchak River and Aniakchak Caldera seen from high bluff in 1922 (W. Smith) and 2006 (G. Frost). Channel migration on the river floodplain is evident below the large boulders at center left. Primary succession after a series of severe volcanic and flood events in the recent past has been very slow outside of the active floodplain. 1922 photo courtesy USGS.

Figure 181. Looking down the Aniakchak River valley just below The Gates in 1930 (B. Hubbard) and 2006 (G. Frost). Since 1930, the active river channel has migrated away from the foreground area; the scarcity of colonizing vegetation suggests that this may have occurred in the recent past. Vegetation at the site prior to the 1931 eruption does not appear to have been extensive. 1930 photo courtesy Santa Clara University.

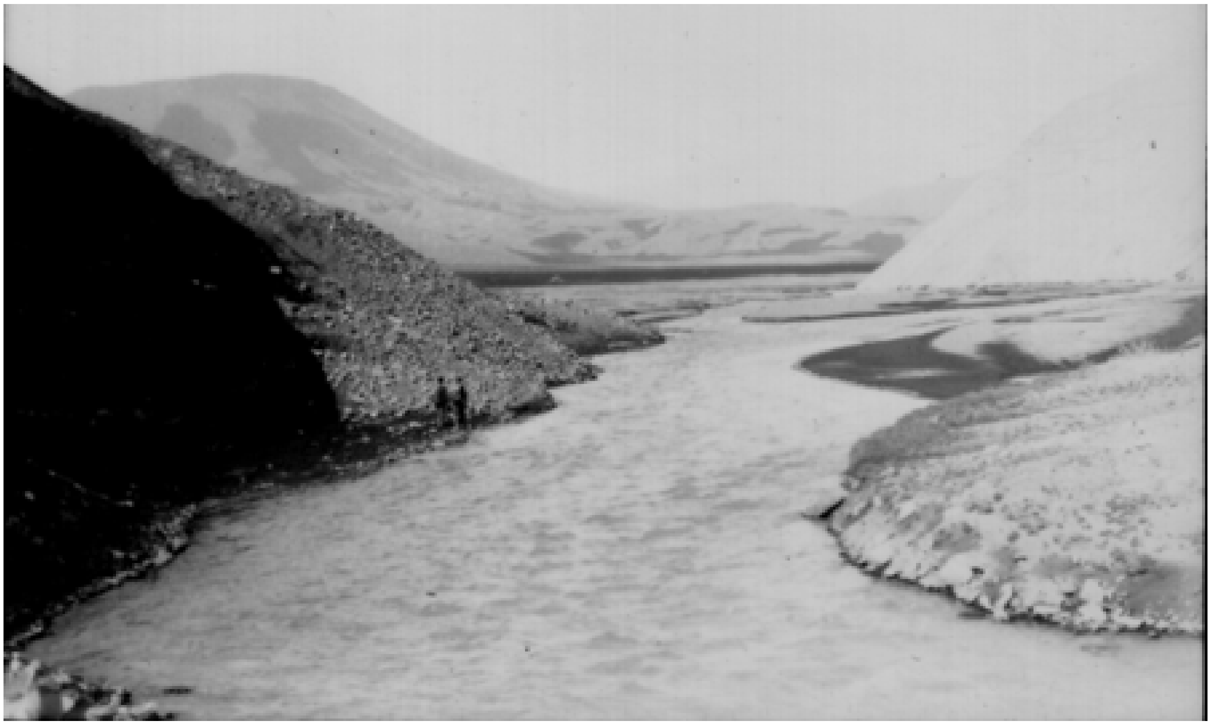

Figure 182. View west into the Aniakchak Caldera from inside The Gates in 1931 (B. Hubbard) and from the same approximate location in 2006 (G. Frost). Channel migration appears to be minor in the background; the island and alluvial fan at background right are still evident. Widespread 1931 tephra has become vegetated in many areas in the background of the 2006 photo. 1931 photo courtesy Santa Clara University.

Figure 183. Outlet of Surprise Lake seen from uplands near The Gates in 1932 (B. Hubbard) and from the same approximate location in 2005 (T. Jones). Little change is evident in the main river channel, but a tributary creek channel has become vegetated. The alluvial flat in the foreground is the most extensively vegetated area in Aniakchak Caldera. 1932 photo courtesy Santa Clara University.

Figure 184. Looking down the Aniakchak River just below The Gates in 1973 (K. Trexler) and 2006 (G. Frost). The active channel has migrated away from the hillside at far right and disturbed the lower portion of the 1973 mid-channel bar. Primary succession has proceeded on persistent portions of the bar, where beach ryegrass and dwarf fireweed (*Chamerion latifolium*) are dominant.

Figure 185. Looking down the Aniakchak River just below The Gates in 1972 (M. Williams) and 2006 (G. Frost). The pace of primary succession has been very rapid after channel migration compared to volcanic disturbance. Floodplain vegetation is dominated by beach ryegrass, Bering's tufted hairgrass, and dwarf fireweed. Increased vegetation cover is also apparent on the hillside in the background.

Figure 186. Aerial view of lower Aniakchak River near Cape Horn in 1972 (K. Trexler) and a similar perspective in 2006 (A. Bennett). The active channel has shifted in the foreground, but channel migration is not apparent downriver. In the foreground, the tributatry creek mouth and a barren 1973 mid-channel bar have become vegetated. Tall shrubs are more abundant on the inactive floodplain at right.

Figure 187. Floodplain of source spring and adjacent lowlands northwest of Surprise Lake, seen from summit of “Vulcan Dome” in 1930 (B. Hubbard) and 2005 (T. Jones). Alluvial depostion of 1931 tephra has filled in the historical northwestern end of Surprise Lake. Other photos in the archive indicate that the shoreline change is not attributable to lower water levels. 1930 photo courtesy Santa Clara University.

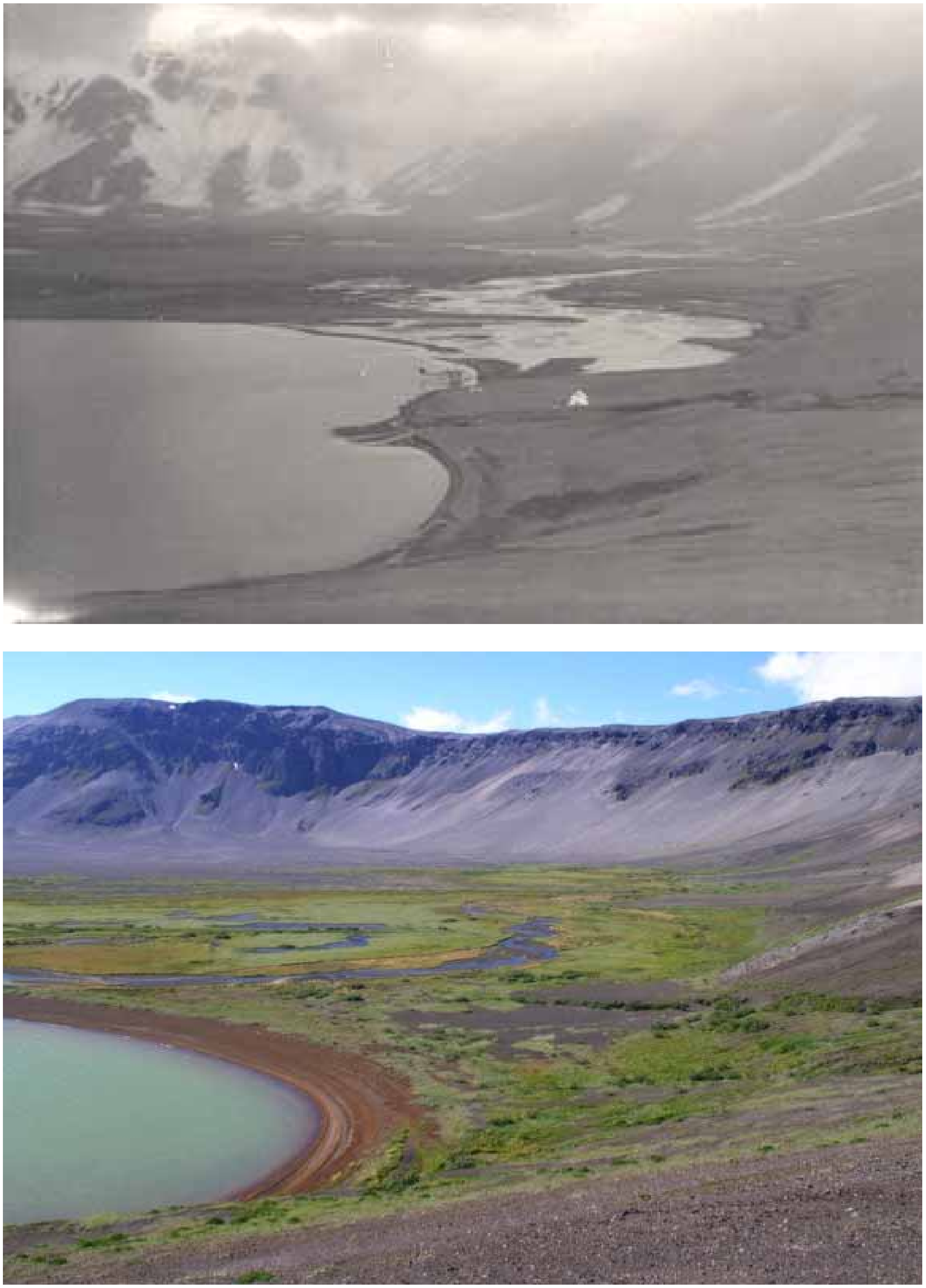

Figure 188. Northwest end of Surprise Lake and floodplain of source spring in 1932 (B. Hubbard) and 2005 (T. Jones). Alluvial deposition of 1931 tephra has modified the lake shoreline. Vegetation has established relatively quickly on the new alluvial surface. 1932 photo courtesy Santa Clara University.

Figure 189. Northwest end of Surprise Lake and floodplain of source spring in 1932 (B. Hubbard) and 2005 (T. Jones). Alluvial deposition of 1931 tephra has modified the lake shoreline. Colonizing willows and graminoids have established quickly on the alluvial flats. 1932 photo courtesy Santa Clara University.

Figure 190. Northwest end of Surprise Lake and floodplain of source spring in 1932 (B. Hubbard) and 2005 (T. Jones). Alluvial deposition of 1931 tephra has modified the lake shoreline. Vegetation has established relatively quickly on the alluvial flats. 1932 photo courtesy Santa Clara University.

Figure 191. Grunert trapping cabin site at Kujulik Bay in 1932 (B. Hubbard) and in 2006 (A. Bennett). Modification of coastal landforms appears to have been limited. Cover of tall willow and alder shrubs has increased at the base of the hillside. Forbs (primarily tall umbels) have become much more abundant in the meadow in the foreground; this area was probably dominated by beach ryegrass in 1932. 1932 photo courtesy Santa Clara University.

Figure 192. Coastal dunes at Aniakchak Bay in 1973 (K. Trexler) and from the same approximate location in 2006 (G. Frost). Comparison indicates beach aggradation and the development of a new foredune (left). Colonization of new surfaces has begun by semi-halophytic species such as seaside sandplant (*Honckenya peploides*), seaside ragwort (*Senecio pseudoarnica*), and beach ryegrass. The 1973 foredune remains dominated by beach ryegrass.

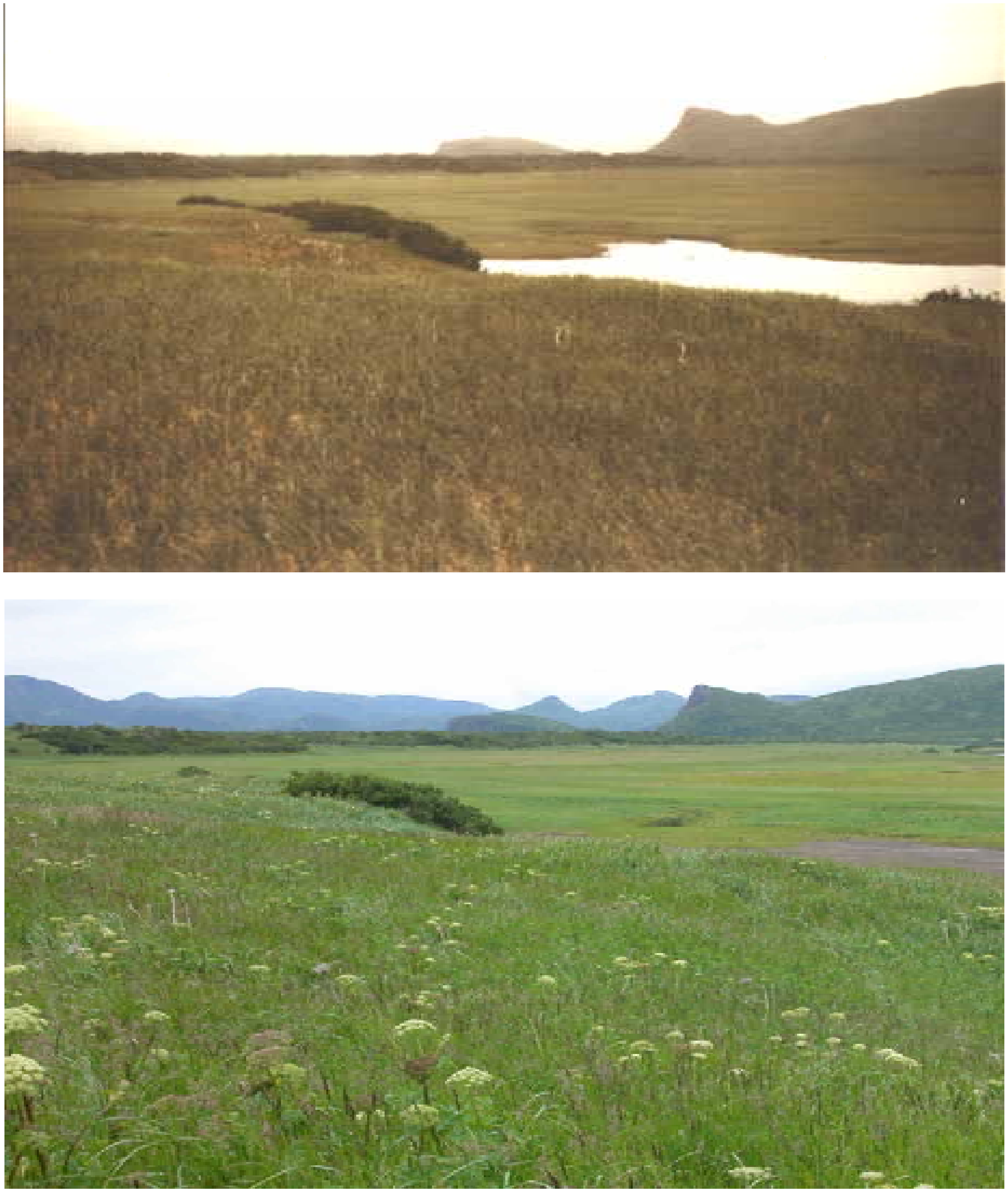

Figure 193. Looking inland from dunes at Aniakchak Bay in 1973 (K. Trexler) and 2006 (G. Frost). No change in alder shrub cover is evident at this coastal site; note the persistence of the herbaceous meadow on the hillside in the left background. Strongly dominated by beach ryegrass in 1973, tall umbel forbs have become much more abundant in the foreground. The semihalophytic wet graminoid meadow in the background appears unchanged; differences in water cover likely reflect variation in tidal stage.

Figure 194. Mouth of Aniakchak River at Aniakchak Bay, seen near high tide in July 17, 1974 (unknown) and at low tide in August 1, 2006 (G. Frost). The coastal spit has shifted position over the 32-year interval and remains barren. In the foreground, forbs (particularly tall umbels) have become much more prominent where low willows (*Salix glauca*) and graminoids were dominant near the standing person in 1974. Little alder expansion is apparent.

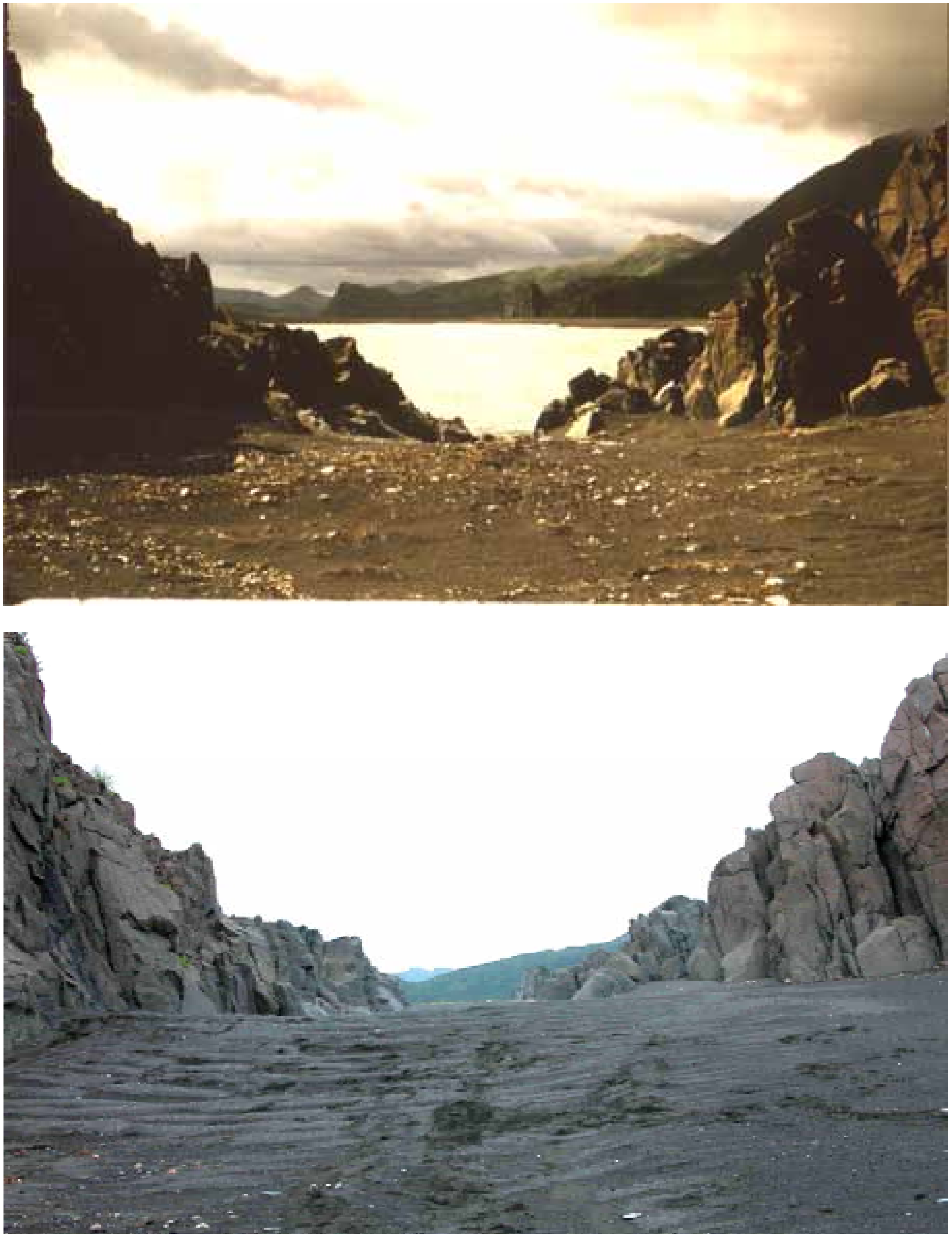

Figure 195. Sand beach and coastal bedrock east of Aniakchak Bay in 1973 (unknown) and 2006 (G. Frost). Comparison indicates erosion of the sand beach. In 2006, the camera had to be positioned ~11 feet off the ground to duplicate the original orientation of the bedrock cliffs and background slopes.