

INCIPIENT GLACIER DEVELOPMENT WITHIN KATMAI CALDERA, ALASKA*

By E. H. MULLER and H. W. COULTER
(U.S. Geological Survey, Washington, D.C.)

ABSTRACT. An unusual opportunity for the study of glaciers in the process of development is afforded in Katmai caldera in south-western Alaska. A violent eruption in 1912 destroyed the summit of glacier-clad Mount Katmai, creating a caldera 4 km. wide and 800 m. deep. Ice cliffs produced by beheading of the glaciers have since thinned and shrunk away from the rim of the caldera, except in the south-west. There, local reversal of direction of movement has resulted in an ice fall which descends part way down the crater wall. In the past thirty years two small glaciers have formed, near 1525 m. above sea level, within the caldera on large masses of slumped wall-rock below the north and south rims respectively. Elsewhere the sheer walls of the crater descend so steeply to the level of the caldera lake that permanent snowbanks cannot accumulate. The lake, which continues to rise at a rate of more than five meters per year, is at present the primary deterring factor in glacier development in the caldera.

ZUSAMMENFASSUNG. Die Kaldera des Katmai in sued-west Alaska bietet eine ungewoehnliche Gelegenheit einen Gletscher im Entwicklungsstadium zu beobachten. Im Jahre 1912 zerstorte eine gewaltige Eruption den Gipfel des gletscherbedeckten Berges Katmai und schuf eine Kaldera, die 4 km breit und 800 m tief ist. Die Eiswaende, die durch das Koeppen des Gletschers gebildet wurden, sind seitdem duenner geworden, und sind, mit Ausnahme der sued-west Seite, vom Kalderarand weggeschrumpft. An der sued-west Seite bildete sich durch oertliche Umkehrung der Bewegungsrichtung des Gletschers ein Eisfall, der teilweise die Kraterwand hinunterreicht. Innerhalb der Kaldera haben sich in den letzten 30 Jahren auf grossen Schutthalden unterhalb der Nord- bzw. Suedkante, zwei kleine Gletscher auf einer Seehoehc knapp unter 1525 m gebildet. An allen anderen Stellen fallen die blanken Waende der Kaldera so steil zum Spiegel des Kalderasees ab, dass sich dauernde Schneefelder nicht bilden koennen. Der See, der immer noch steigt, und zwar jaehrlich mehr als fuef Meter, ist gegenwaertig das Haupthinderniss fuer die Vergletscherung der Kaldera.

GLACIERS develop so gradually that only rarely does one have an opportunity to study a glacier *in statu nascendi*. Such opportunity exists within the caldera produced by the 1912 eruption of Katmai volcano (lat. $58^{\circ} 17' N.$, long. $155^{\circ} 0' W.$) in south-western Alaska (Fig. 1, p. 15). Within 20 years after formation of the caldera permanent ice fields had formed below the north and south rims. These small glaciers and other features related to the glaciation of the caldera are here described as observed by the writers in 1953.†

Acknowledgment is made of the assistance of G. H. Curtis in furnishing unpublished data from observations on Katmai volcano in 1953 and 1954. Logistical support was provided in the field by the Katmai project of the National Park Service. Photographs of Katmai caldera taken by the Griggs Expeditions are reproduced by courtesy of R. F. Griggs and the National Geographic Society.

PREVIOUS INVESTIGATIONS

Griggs¹ summarizes information on the Katmai district prior to the great eruption of 1912. The record of activity during the violent phase of this eruption has been interpreted by Fenner² and more recently by Williams³. Early in June 1912 pumice and ash were scattered widely and massive deposits of welded tuff were laid down by incandescent avalanches in the valley of Knife Creek (Fig. 1). The total volume of ejecta from Katmai crater and subsidiary vents has been estimated at more than 30 cubic km.¹ Three days of violent eruption culminated in collapse of the summit of Mount Katmai. Where a glacier-clad peak had risen 2285 m. above sea level, there remained only a gaping caldera with jagged rim, as low as 1525 m. above sea level in places.

Griggs reported that six years after the eruption ash cover remained "still undisturbed near the crater rim, where glacier motion was slow, but dumped among the seracs and crevasses where the glacier was moving more rapidly". Ice cliffs, the exposed ends of beheaded glaciers, stretched for several miles along the westerly and northerly sides of the crater.

* Publication authorized by the Director, U.S. Geological Survey.

† The immediate vicinity of Mt. Katmai is covered by the A-3, B-3, A-4 and B-4 topographic sheets on the scale of 1:62,500 with 100 foot contour interval, released by the U.S. Geological Survey subsequent to preparation of this manuscript.

In 1923 Fenner⁴ and Yori descended to the floor of the caldera over snow fields which filled a gorge on the south-west side. Fenner describes rubble accumulations 1800–2400 m. high at the south and north ends of the caldera. Figs. 12 and 17 of Fenner's paper⁴ clearly show these slumped masses, with limited snow fields in the hollows but showing no evidence of incipient glacier development. Some time after 1923 a permanent, though local, ice field accumulated on the slumped rubble at the south rim of the caldera. In 1935 Hubbard observed that ". . . the glaciers we had noticed four years earlier forming on the inner sides of this great hole were larger and more active, cascading in beautiful icefalls down to the edge of the lake"⁵.

INFERRED CLIMATIC CONDITIONS

The nearest regularly reporting meteorological stations are King Salmon (Naknek Air Field), 65 miles (105 km.) west-north-west of Katmai volcano, and Kodiak, 80 miles east-south-east. In the absence of observational data within the Aleutian Range, one can do no better than to estimate conditions based on data from these two stations. Thompson⁶ concludes by interpolation between King Salmon and Kodiak that mean sea level temperature near Mount Katmai is 3–4° C. Southerly circulation of moist, maritime Pacific air prevails. If, because of this prevalence, the average temperature lapse rate approaches the moist adiabatic (about 1.3° C. per 1000 ft.), mean temperature at the caldera rim may average about –5° C. Temperature may average above freezing for several months during the summer, with more than 5° C. during the warmest month.

Precipitation data for sea level stations are meaningless for the summit area of Katmai, but precipitation of much more than 250 cm. per year is indicated by the very limited data for mountain stations elsewhere in the coastal ranges of Alaska. Indirect evidence of the amount of precipitation may be obtained from the annual rise of level of the caldera lake. If the annual net increase in depth of the lake may be assumed to be entirely due to accumulation of meteoric water, the excess of precipitation over evaporation is at least 200 cm. per year. Regional snow line is near 1675 m. above sea level, but in particularly favorable locations the local snow line dips as low as 1375 m.

OBSERVATIONS IN 1953

Four features related to glacier development within the caldera attracted attention in 1953: (a) continued development of the small glacier below the south rim; (b) complete wastage of rimming ice cliffs, except at one point where a steep ice fall into the caldera results from reversed direction of movement at the edge of a beheaded glacier; (c) incipient glacier formation below the north rim; and (d) marked rise in lake level.

The small glacier below the south rim of the caldera (Fig. 2, p. 17) developed on a bench illustrated by Fenner⁴ and mapped by Maynard¹, which formed apparently by slumping of massive blocks of wall-rock. The caldera rim is bare of ice for more than 30 m. above the small glacier, indicating that snow accumulation by drifting is an important factor in its nourishment. No bergschrund was noted, and seasonal snow accumulation obscured all evidence of movement of the upper portion of the ice body. The glacier surface forms a smooth curve, concave upward above 1375 m. and convex below, reflecting the underlying contours of the mass of slumped wall-rock. Both east and west of a nose of bare slump material, the glacier calves into the lake. Sheer ice cliffs, estimated to be 50 to 80 m. high, are bordered by a concentric pattern of deep crevasses. As the main body of the glacier was blanketed with seasonal snow and 1–2 cm. of black ash from the 1953 eruption of nearby Trident volcano, these ice cliffs with their associated crevasses provided the only readily apparent evidence that this is indeed a small glacier rather than an ice field without motion. The over-all effect is suggestive of an ice body barely thick enough to attain marked plasticity, except in areas of steep surface gradient near the two actively calving faces.

Extensive ice cliffs, which rimmed the caldera west of the small glacier in 1918, have thinned and melted back, exposing bare rock and pyroclastic debris for some distance (Fig. 2). Although

it is near the regional snow line, this portion of the rim is exposed to winds which prevent snow accumulation. At only one place, in the south-west, does a tongue of ice cross the caldera rim to descend in a striking, deeply crevassed ice-fall halfway to lake level. This ice fall presumably owes its existence to reversed movement of part of a glacier beheaded by the 1912 eruption, and only a fortuitously located minor scallop in the caldera rim favors its preservation and development.

A large mass of slumped wall-rock, similar to that on which the south-rim glacier developed, occurs on the north side of the caldera (Fig. 3, p. 17). Sheer cliffs drop more than 150 m. from the rim, providing an avalanche area to feed the snowfields on more gentle slopes below. The southerly exposure of the accumulation area, most of which is below the regional snow line, operates to delay glacier development. When observed in 1953, this ice field was so covered with seasonal snow and a blanketing of recent ash from Trident volcano that all evidence of possible movement was obscured. An air photograph taken by Mr. Robert Spring (Fig. 4, p. 17) in late summer, 1954, clearly shows dirt bands at the western margin, where the small glacier terminates 50-100 m. above the lake. From the eastern edge of the glacier an ice fall descends almost to lake level.

At present the only permanent bodies of ice within Katmai crater are the small glaciers on slumped masses of wall-rock, below the rim at the north and south edges of the caldera, and the ice fall from the south-west rim*. The east wall in particular, and parts of the west wall as well,

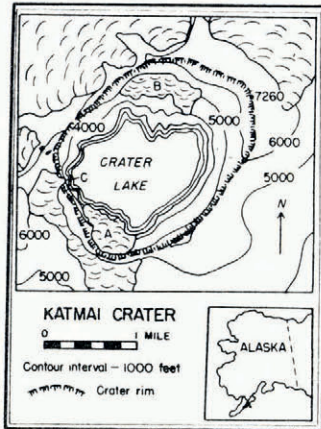


Fig. 1. Index map of glacial features of Katmai calderas
 A. South rim of glacier
 B. North rim of glacier
 C. Ice fall into caldera
 Inset shows location of Katmai volcano
 Adapted from the U.S. Geological Survey Mt. Katmai sheet, 1: 250,000

drop sheer to lake level and afford no opportunity for the collection of avalanche material. The one small glacier which reaches lake level wastes rapidly through contact with the warm waters. The role of the volcanic lake as a deterrent to glacier development in the caldera is apparent.

When first observed by the Griggs Expeditions, the caldera contained a lake more than 1.6 km. in diameter, with a small crescentic island. In 1923 Fenner walked over the floor of the caldera where the lake had been and studied at close range the geyser-and-mud volcano activities which were manifestations of waning volcanism. The breached cone, which had formed the crescentic island, stood about 20 m. above the caldera floor, giving an approximate indication of the volume of water which had been lost in draining of the lake.

By the early 1930's, however, subterranean drainage had decreased and a lake had again collected in the caldera bottom. In the 25 or 30 years since that time lake level has apparently risen steadily, and the lake is now probably more than 150 m. deep. Comparison of air photographs taken in 1951 with low-angle oblique shots in 1953 suggests a continuing rise of 5 m. or more per

* From earlier accounts of the snow accumulations on Mt. Katmai there appeared to be some doubt as to whether a true glacier was in fact developing. Correspondence with Professor Muller after receipt of his paper left no doubt that a measurable glacier regime, and little doubt that flow, are taking place. *Ed.*

year (G. H. Curtis, personal communication). Bush pilots report that even in mid-winter the lake remains unfrozen, testifying to the residual heat still retained within the caldera. Sumner⁷ observed a sluggish churning of the waters, suggestive of deep convection currents. Evidence of the temperature and movement of the lake water was afforded by the drift of small icebergs from the west side of the southern small glacier (Curtis, personal communication). Although the lake surface was unruffled by the wind, the iceberg train drifted steadily eastward to within a few hundred yards of the eastern cliffs, thence northward parallel to the shore. Within about seven hours most of the floating ice fragments had melted. Perhaps it is more than coincidence that similar drift is evident in air photographs taken three years previously.

For the future, one may well wonder whether the caldera will in time become completely ice-choked, like the smaller caldera in Veniaminof volcano to the south-west. In all probability the caldera lake will for many years to come play a controlling role in delaying glacier development. If lake level continues to rise in response to annual precipitation increments comparable to those from 1923 to 1953, the lake may be expected to overflow the caldera rim through the east notch, at an elevation near 1525 m. above sea level, in about 100 years. Even though active volcanism may have ceased, residual heat will be very slow in dissipating. The deep lake is a thermal reservoir which will deter glacier growth as long as the lake persists. On the other hand, the regional snow line so nearly passes above a large part of the caldera rim that the small glaciers within the caldera will remain very responsive to minor climatic changes.

In view of the unique opportunity for study of glacier development, it is hoped that a more complete record of lake level changes and glacier growth within Katmai caldera may be obtained in future years.

MS. received 18 October 1955

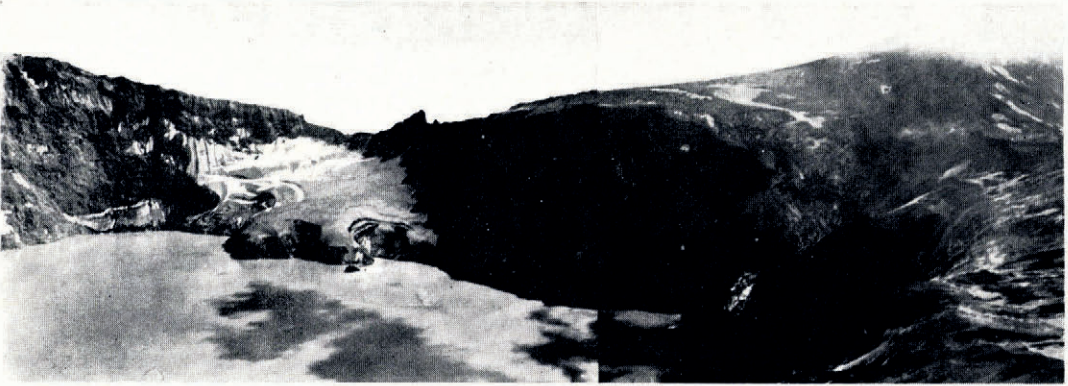
REFERENCES

1. Griggs, R. F. *The Valley of Ten Thousand Smokes*. Washington, National Geographic Society, 1922. 341 p.
2. Fenner, C. N. The origin and mode of emplacement of the great tuff deposit of the Valley of Ten Thousand Smokes. *National Geographic Society Contributed Technical Papers* No. 1, 1923, p. 1-74.
3. Williams, H. Preliminary note on geological work done on Mount Katmai and in the Valley of Ten Thousand Smokes. (*In Interim report, Katmai Project*. Washington, National Park Service, 1953, p. 55-62.)
4. Fenner, C. N. Mount Katmai and Mount Mageik. *Zeitschrift für Vulkanologie* (Berlin), Bd. 13, 1930, p. 1-24.
5. Hubbard, B. R. Cradle of the storms. New York, Veil-Ballou Press, 1935. 283 p.
6. Thompson, W. F., Jr. Katmai geographic studies. (*In Interim report, Katmai Project*. Washington, National Park Service, 1953, p. 26-50.)
7. Sumner, L. Magnificent Katmai. *Sierra Club Bulletin*, Vol. 37, 1952, p. 29-52.

Fig. 2 (opposite, top). South wall of Katmai caldera in 1953. At the left, sheer cliffs rise 500 m. above the caldera lake. The small glacier has formed in the past 30 years on a mass of slumped wall-rock. At the right an ice fall descends into the crater at the only point where the crater rim is covered by ice. Elsewhere ice cliffs, which resulted from beheading of glaciers during the eruption of 1912, have thinned and shrunk away from the caldera rim. The lake is about 150 m. deeper than in Fig. 3

Fig. 3 (opposite, centre). North wall of Katmai caldera a few years after the eruption of 1952. The cliffs rise about 1100 m. above the lake, which was then only 15-20 m. deep. Note the shrinking ice cliffs along portions of the crater rim at left. In recent years a small glacier has formed on the mass of slumped material where perennial snow had already begun to accumulate at the time of this photograph
(Photograph by J. D. Sayre, courtesy of National Geographic Society.)

Fig. 4 (opposite, bottom). North wall of Katmai caldera in 1954. Compare with the similar view in Fig. 3, taken 36 years earlier. Note marked development of the small north rim glacier and rise of lake level in the interval, while beheaded glaciers on the outer slopes of Katmai volcano have thinned conspicuously
(Photograph by courtesy of R. and I. Spring, Seattle.)



2 +