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KATMAI CALDERA: GLACIER GROWTH, LAKE RISE, AND GEOTHERMAL ACTIVITY

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INTRODUCTION

Mt. Katmai (2,047 m), located on the Alaska Peninsula in Katmai National Monument, is part of the extensive Aleutian arc system of active and sometimes violent volcanism (fig. 1). On June 6, 1912, the Katmai area was devastated by one of the largest and most dramatic eruptions in recorded history. Pumice and ash were scattered over broad regions and massive pyroclastic flows filled the valleys of Knife Creek and Lethe River, forming the famed Valley of Ten Thousand Smokes. Three days of violent eruptions culminated in the creation of the Mt. Katmai collapse caldera. The subsequent formation of a crater lake, development of intracaldera glaciers, and continuation of geothermal activity within the caldera have been documented by various investigators. The current study was undertaken to determine what changes have occurred within the caldera since Muller and Coulter's (1957) observations of 1953. Field work in August 1974 and July 1975 included resurveying the lake surface elevation, collecting water samples for geochemical analysis, taking lake-temperature measurements, and observing the growth of the lake and glaciers.

EARLY OBSERVATIONS

The 3- by 4-km Katmai caldera and crater lake were first viewed in July 1916 by Robert Griggs and his Katmai expeditionary party (Griggs, 1922). Steep, nearly vertical walls rose 600 to 1,000 m above a milky turquoise-blue lake. Large slump masses and huge rubble accumulations were present along sections of the northern and southern walls of the caldera; the rim of a volcanic cone protruded above water level near the center of the lake, evidence of postcaldera eruptive activity. The caldera was mapped and the elevation of the lake was determined in 1917 during Grigg's second Katmai excursion. Fenner and Yori visited the Katmai caldera in July 1923 (Fenner, 1930) and found the lake had drained. They descended to the caldera floor and examined the numerous mud pots, thermal springs, and fumaroles that still emanated from the relatively flat lake bed. The volcanic cone was quiescent, but a mud geyser, 30 m in diameter, was violently erupting in the northeastern part of the lake bed. Hubbard (1935) during the late 1920s and 1930s documented the refilling of the lake and the growth of permanent snow fields on the northern and southern slump masses. The lake continued to rise, attaining an elevation of 1,188 m by July 1951 (USGS topographic map, Mt. Katmai B-3, Alaska), an increase of 182 m in 28 years. By 1953 the snowfields on the slump masses had developed into glaciers, with the southern one reaching lake level (Muller and Coulter, 1957) and a third one flowing into the northwestern part of the caldera as the result of flow reversal in a glacier beheaded by the 1912 caldera collapse. By comparing aerial photographs taken in 1951 and 1953, Muller and Coulter estimated that the lake was still rising at a rate of more than 5 m per year.

RECENT OBSERVATIONS

Observations in 1974 and 1975 documented the continued growth of the glaciers and rise in lake level (fig. 2). At least 42 annual snow layers were counted in an exposed headwall of the south glacier, indicating an onset of glacier development at least by the early 1930s. All three glaciers terminate at the lake and calving occurs at several locations. The warm waters of the volcanic lake are now inhibiting any further glacier growth, and if lake level continues to rise, significant glacial ablation will probably result. However, the lake level may be stabilizing.

In August 1974 a survey of the crater lake from fixed points on the caldera rim determined the lake surface to be 1,235 m in elevation, an increase of only 47 m in the 23-year period beginning in 1951. The significantly lower rates of recent years contrast sharply with the pre-1953 rates (table 1); the increase of lake surface area with height is much too small to account for this sharp growth-rate decrease. On the basis of estimates of lake volume increases and drainage area, the 6.6-m/yr rate corresponds to 200-250 cm annual precipitation, reasonable for this coastal environment. The 2-m annual increase corresponds to an annual precipitation of 30 to 80 cm, which is low. The exact cause of the sharp decrease in lake-level rise is unknown. Perhaps at higher lake levels the pressure head is sufficient to cause considerable seepage through the Jurassic sandstones and shales of the Naknek Formation beneath the volcanic rocks. From comparison with Grigg's original map, present lake depth is estimated to be 230 m.

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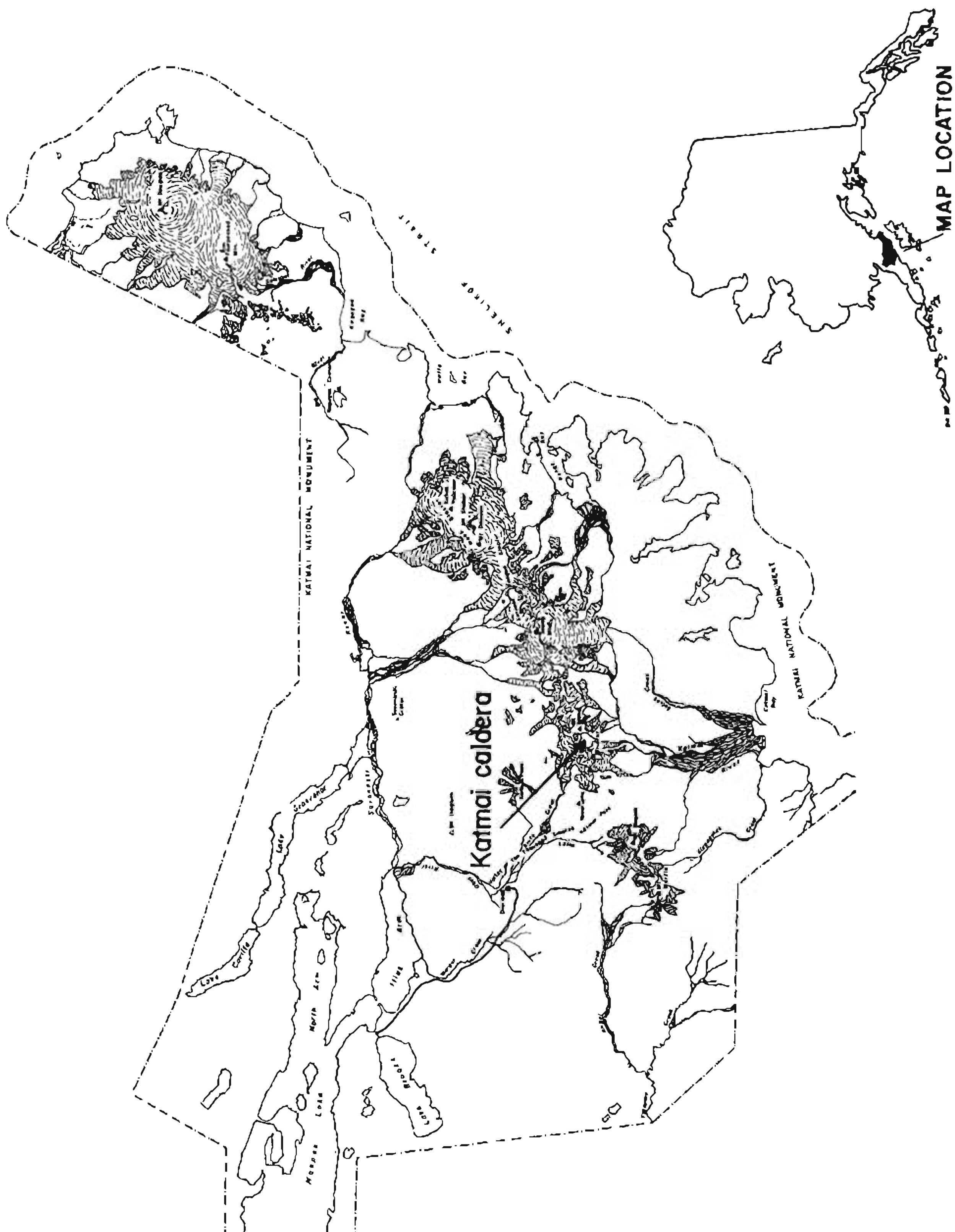
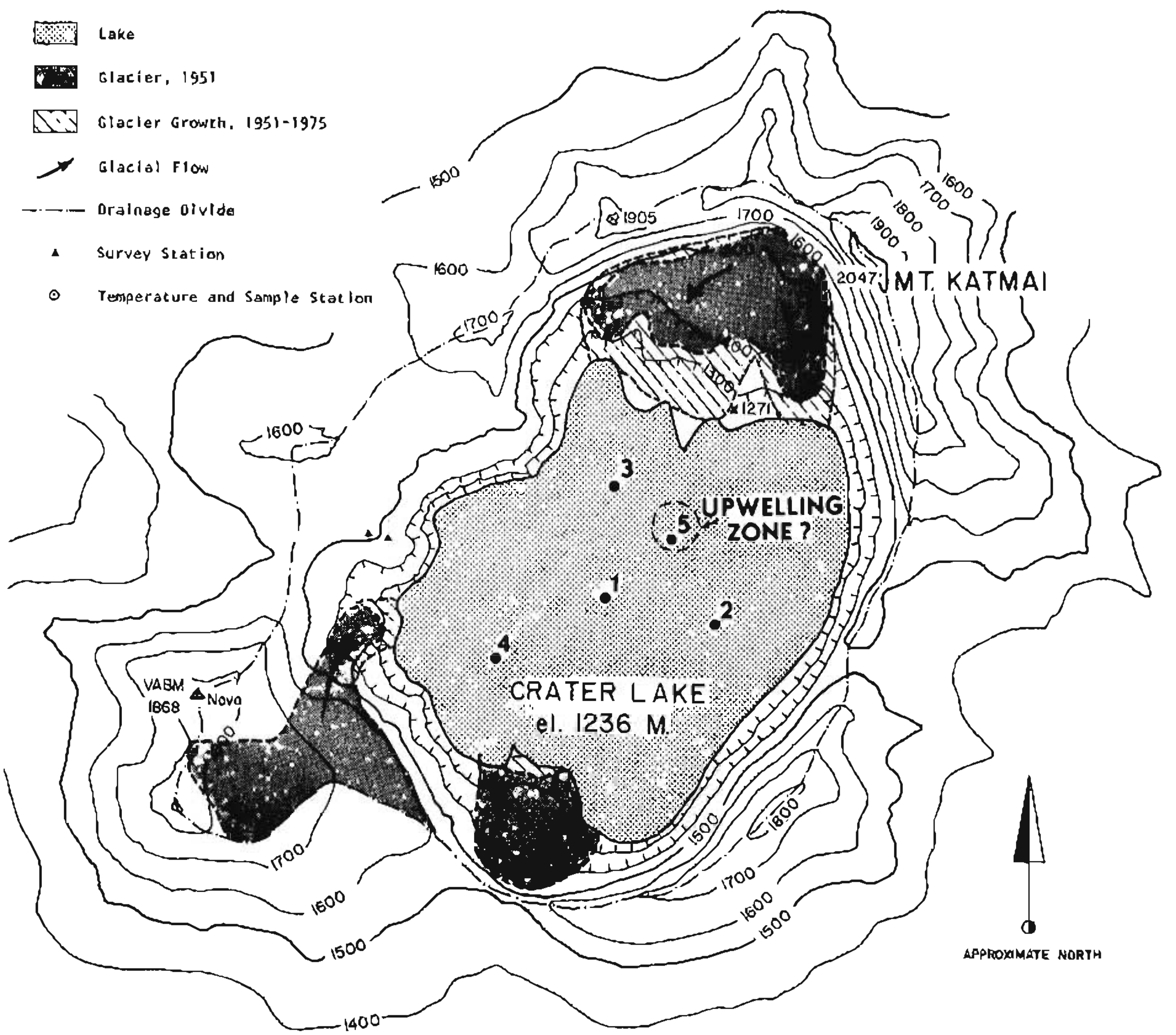


Figure 1. Location of Mt. Katmai caldera.

THERMAL REGIME, KATMAI CRATER LAKE

From interviews with local pilots who observed the lake to be unfrozen in midwinter, Muller and Coulter (1957) concluded that residual heat was still retained within the caldera. Evidence gathered in early July 1975 indicates that geothermal activity continues to affect the lake. Several stations on the lake surface were located by resectioning from several conspicuous peaks along the caldera rim. Because the inflated raft used for transportation was susceptible to wind drifting, station locations are considered rough approximations. Temperature measurements were made with a protected reversing thermometer from the surface to depths of 60 m at locations 1, 2, 3, and 5 and to 40 m at location 4 (fig. 2). The temperature profiles in four of the locations were very similar, with average temperatures of 5.3°C at 60 m and 5.8°C at 10 m (fig. 3). By using the average temperature gradient of 0.005°C/m for the 40- to 60-m depth range as representative of the entire water column, the estimated bottom temperature is about 4.5°C, which is above the temperature at which water has its highest density (4.0°C).

An estimate of the 1974-1975 crater-lake heat budget



Base from U. S. Geological Survey, 1951, Katmai quadrangle, Alaska; and 1974, 1975 observations.

0 500 1000 METERS

CONTOUR INTERVAL 100 METERS

Table 1. Summary of lake level changes, Mt. Katmai crater lake

Year	Approx. lake depth (m)	Est. annual change (m)
1917	10-15	2-3
1923	0	?
1951	182	6.6
1953	- - -	5[a]
1974	229	2
1975	230	1.2[b]

[a]Estimated photo comparison (Muller and Coulter, 1957).
[b]Measured by field survey.

was made by using Michel's (1971) model for the thermal regime of deep lakes. Weather conditions at the caldera were extrapolated from weather data at King Salmon and Kodiak. A conservative lapse rate of 0.43°C/100 m was used for determining caldera air temperatures. The results of the analysis indicate that even when conservative estimates were made for all the various heat-budget factors, the July lake temperatures were still abnormally high, implying a source of heat still present at depth.

Station 5 was approximately centered over a zone of yellowish discoloration about 100 m in diameter that was easily seen from the caldera rim and which roughly coincides with the location of Fenner's "mud geyser" (1930). A temperature of 5.5°C was measured at depths of 10 and 60 m, indicating upwelling and thermal mixing. The yellowish color of this zone was caused by a dense stream of small sulfur particles that appeared to be rising from a subaqueous source. The areal extent, appearance, and location of the discoloration varied, sometimes disappearing completely for several minutes or more. This zone had a markedly different character in August 1974, appearing as a large boil of water, as if due to upwelling. The high concentrations of sulfur in this and several other areas of the lake were accompanied by continuous bubbling activity and heavy odors of hydrogen sulfide and organic gas. A pH of 2.5-3.0 was measured at all locations. Table 2 gives the geochemical analyses of water samples obtained from 60 m depth at stations 5 and 2.

Extrapolations of average temperatures from King Salmon and Kodiak indicate that the surface of the crater lake should normally freeze by early winter at the latest. The presence and growth of glaciers within the caldera also indicate a relatively cold climate. However, ERTS images taken February 11 and March 19, 1975 show the lake surface free of ice, providing further evidence of geothermal activity. However, an aerial photo taken March 14, 1967 shows the lake almost completely frozen over. The 1966-67 winter temperatures were about normal at King Salmon and Kodiak, but the 1974-75 winter temperatures were considerably below average. The lack of lake ice during an especially cold winter may indicate that Mt. Katmai is in a state of thermal fluctuation or is beginning to warm up. Significant changes in water temperatures of crater lakes preceded recent eruptions at Ruapehu Volcano, New Zealand (Dibble, 1974) and Taal Volcano in the Philippines (Minakami, 1974). Continued monitoring of Katmai crater lake appears warranted.

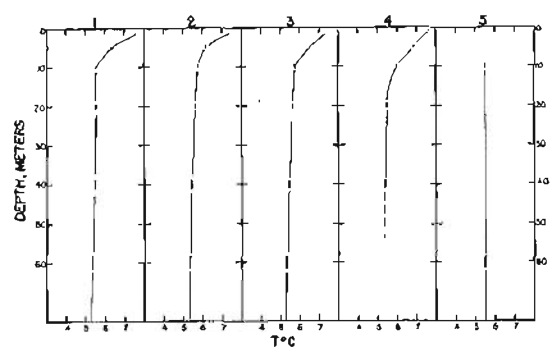


Figure 3. Temperature-depth profiles at five locations in Mt. Katmai crater lake, July 7-8, 1975. (See fig. 2 for station locations.)

Table 2. Chemical analysis of water samples from Mt. Katmai crater lake (ppm)

Location[a]	SiO_2	H	Ca	Mg	Na	K	Li	SO_4	Cl	F	B
2	120	8.9	300	51	760	90	0.92	1250	1350	0.9	12
5	140	11.4	300	62	590	110	1.2	1200	1750	1.1	14

[a]See Figure 2.

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