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SURVEILLANCE OF KATMAI CALDERA AND CRATER LAKE, ALASKA: 1977

Final Report on U.S. National Park Service Purchase Order PX 9100-7-1009

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INTRODUCTION

Mt. Katmai (2,047 m), located on the Alaska Peninsula in Katmai National Monument (Fig. 1), is part of the extensive Aleutian arc system of active and sometimes violent volcanism. 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 well documented by various investigators: Griggs, 1922; Fenner, 1930; Hubbard, 1935. Muller and Coulter (1957) in 1953 observed the continued growth of three intra-caldera glaciers and continued rise in crater lake level. More recently the author undertook a study to determine what changes had occurred within the caldera since 1953. Field work in August 1974 and July 1975 included a survey of crater lake surface elevation, geochemical sampling, lake temperature measurements, and various observations on the growth of the lake and glaciers. These studies were summarized by Motyka (1977) and serve as a baseline to judge and evaluate future changes in the crater lake and intra-calderan glaciers.

OBJECTIVES OF SURVEILLANCE

The 1977 field work and observations summarized in this report, in-augurate a National Park Service sponsored program in cooperation with the Geophysical Institute, University of Alaska, of periodic Katmai volcano

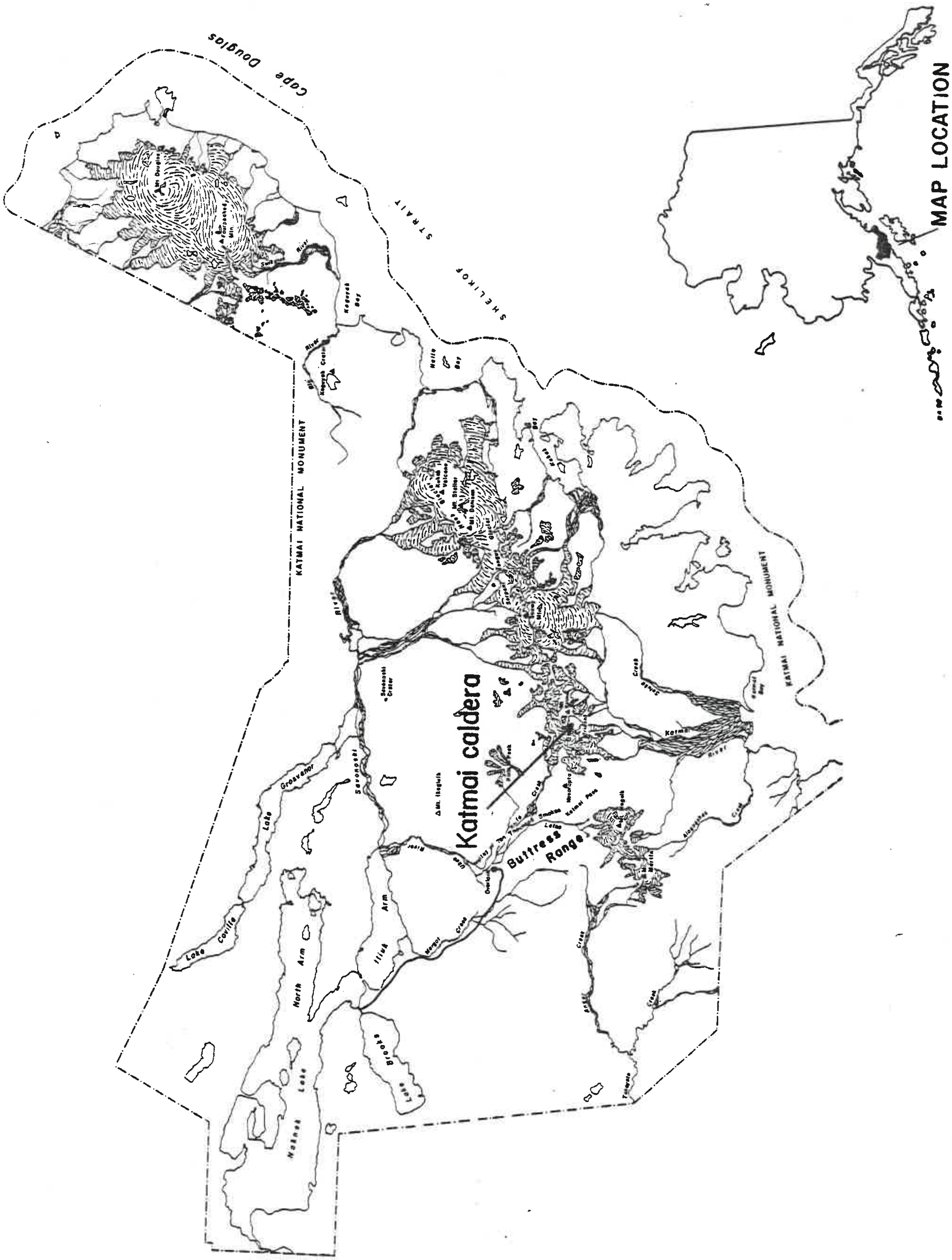

Figure 1. Location of Mt. Katmai caldera.

surveillance. There are two closely related objectives of the study: the first is to understand the hydrologic-glaciologic budget and balance of Katmai Caldera; the second is to monitor changes in geothermal activity. The significance of the first objective lies in the uniqueness of the volcanic lake and glacier system at Katmai and the youthfulness of the intra-caldera glaciers. These glaciers which developed after the 1912 eruption are the only known instances where glacier development has been observed from inception. Because the glaciers all presently terminate at the volcanic lake the lake hydrology has a direct effect on the continued growth of these intra-caldera glaciers. Ice-calving presently inhibits glacier growth, and ablation will increase significantly as the lake level continues to rise.

The importance of the second objective is that significant changes in geothermal activity have preceded eruptions of other volcanoes with crater lakes (Dibble, 1974; Minakami, 1974). Evidence gathered during 1974 and 1975 showed that Katmai Crater lake is still geothermally active and may, in fact, be warming up (Motyka, 1977; Motyka and others, 1977). Baselines for lake level, water temperatures and water chemistry have now been established and significant changes in any of these parameters could signal the onset of renewed eruptive activity. Continued observations and measurements might allow identification of volcanic risks and serve to alert the National Park Service to a potentially hazardous condition. Although the above objectives are listed separately they are closely related because changes in geothermal activity will most likely affect the hydrologic parameters controlling the rate of lake-level rise.

1977--OBSERVATIONS AND RESULTS

General Remarks: Two weeks were spent in active field work at Mt. Katmai during August, 1977. Although often frustrated by bad weather, most of the planned tasks were accomplished. During a three day break in weather, 20 August to 22 August, observations were possible from the caldera rim and a descent was made onto the crater lake via the west saddle (Figure 2). This descent to lake level has become increasingly hazardous owing to an increase in lake level. The only reasonably accessible and useable boat launch area now lies in the path of a natural avalanche chute. Crater lake measurements were made from an inflatable kayak.

Hydrology: An in-place water level marker located near the terminus of the west intra-caldera glacier (arrow in Figure 2) showed a total lake level rise between 5 July 1975 and 20 August 1977 of 6.5m. The average annual rate of increase of 3 m yr^{-1} is significantly higher than previous years (1.2 to 1.6 m yr^{-1}) and may be due to the abnormally high precipitation which occurred during the winter of 1977. August, 1977 lake level elevation is estimated at 1242 m. (The lowest points along the caldera rim are located at the west and east saddles and are both approximately 1450 to 1490 m in elevation.)

Depth sounding of Katmai Crater Lake in the vicinity of the zone of upwelling (Figure 2) revealed a water depth of 190 to 200 m. A second sounding obtained near the center of the lake (under duress of approaching bad weather) gave a depth of 150 m $\pm$ 10 m. Deteriorating weather prevented additional soundings. The first and deeper sounding gives an estimated caldera floor elevation of 1040 m at this point. This elevation is at

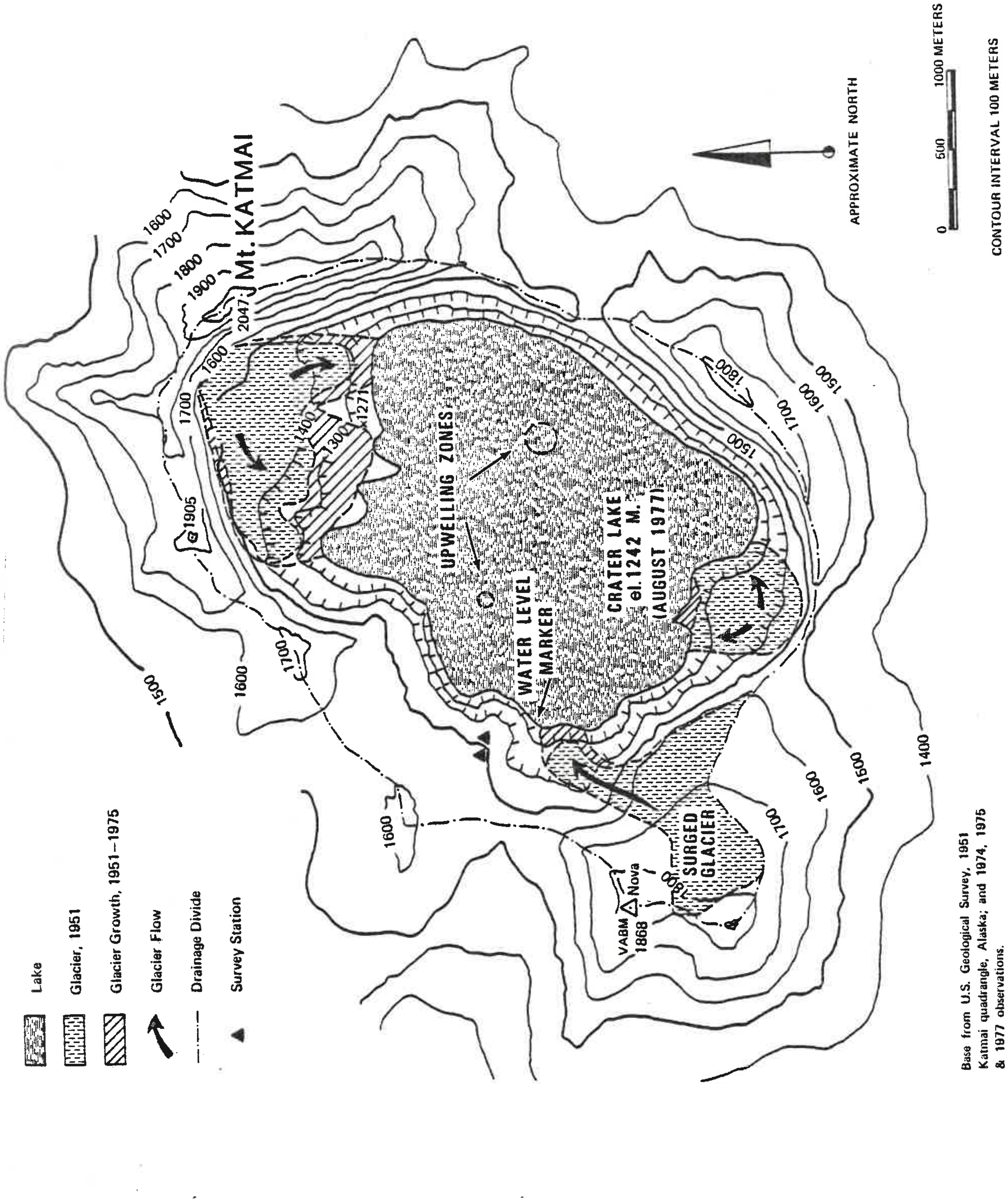

Figure 2. Katmai Caldera and Crater Lake (revised from Motyka, 1977).

variance with Maynard's* 1917 survey of the crater lake surface elevation which is given as 1000 m, cf. back cover foldout map, Griggs, 1922. Although the 1917 crater lake depth is unknown, it probably did not exceed 10-20 m (Fenner, 1930; Motyka, 1977). This would place the caldera floor at about 980 to 990 m elevation giving a discrepancy of 50-60 m. Part of the discrepancy could be attributed to uncertainties in elevations of control points used in Maynard's survey and, in fact, elevations Maynard assigned to three peaks along the caldera rim differ from the 1951 USGS topographic maps by amounts of 8, 20, and 86 meters, with Maynard's estimates consistently higher.

Another measurement, one which tends to corraborate the first and deeper sounding comes from Fenner (1930) who used an aneroid barometer during a descent onto the caldera floor in 1923 (the crater lake had drained sometime between 1919 and 1923). Although the absolute accuracy of Fenner's barometer is unknown, the relative elevation change of 490 m registered by his barometer in descending from the low point on the western saddle to the caldera floor is probably accurate to ± 10 m. Recent photogrammetric measurements made in cooperation with North Pacific Aerial Surveys (NPAS) of Anchorage give an elevation of 1516 m (± 5 m) for the west saddle low point in 1951. The ash covered saddle is cored by glacier ice, however, and a thinning of 15 m was photogrammetrically measured for the period 1951-1975. If we assume a similar rate of thinning for the period 1923 to 1951 then the saddle would have been at an elevation of 1531 m or more, placing the 1923 caldera floor, according to Fenner's relative measurements, at about 1040-1050 m.

*Maynard was the project topographer on the National Geographic Society expeditions to Katmai in 1917 and 1919 (Griggs, 1922).

The shallower 150 m depth sounding near the center of the lake is more difficult to reconcile particularly since Fenner's photos clearly show the caldera floor to be relatively flat except for a volcanic "crescentic island" near the center of the floor (Fenner, 1930; see also Griggs, 1922). The sounding may have by chance been made over part of this island which is some 400 m in diameter and approximately 20 m high. Unfortunately wind and wave conditions did not allow an accurate determination of the position of the sounding measurement in 1977, and no correlation can be made.

Some of the difference in elevation might also be explained by infilling of sediments washed down from the caldera rim and also, the possibility of at least a minor sub-lacustrine eruption cannot be dismissed. The region is remote and rarely visited until recent times. A small scale volcanic eruption could have easily gone unnoticed and could also explain the apparent change in the rate of lake level rise shown in Table 1.

Our recent photogrammetric measurements of Mt. Katmai provide a more accurate estimate of the lake level elevation in 1951 than had been previously obtainable from the USGS topographic maps of the region. A revised table of crater lake level changes incorporating these and other new results is provided in Table 1.

Glaciology: The intra-caldera glacier located on the west side of the caldera has surged (Figure 3). This glacier, which lies immediately to the south as one descends down into the caldera from the west saddle (Figure 2), is now extremely crevassed and broken with numerous seracs

TABLE 1. KATMAI CRATER LAKE: SUMMARY OF SURFACE ELEVATION AND WATER DEPTH CHANGES

DATE	LAKE SURFACE ELEVATION	LAKE DEPTH	ANNUAL RISE IN LAKE LEVEL	SOURCE OF INFORMATION
1917	?	10-20m	2 to 4m	Griggs (1922), see also Motyka (1977) and text.
1923	1040-1050m	0	-1.5 to -3.5m	Fenner (1930); NPAS* (see text).
1951	1200m	160m ?	5.7m	NPAS Photogrammetric measurement.
1974	1235m	190m ?	1.6m	Elevation surveyed, Motyka (1977).
1975	1236m	191m ?	1.2m	Lake level marker, Motyka (1977).
1977	1242m	150-200m	3m	See text.

*North Pacific Aerial Surveys, Inc., Anchorage, Alaska.

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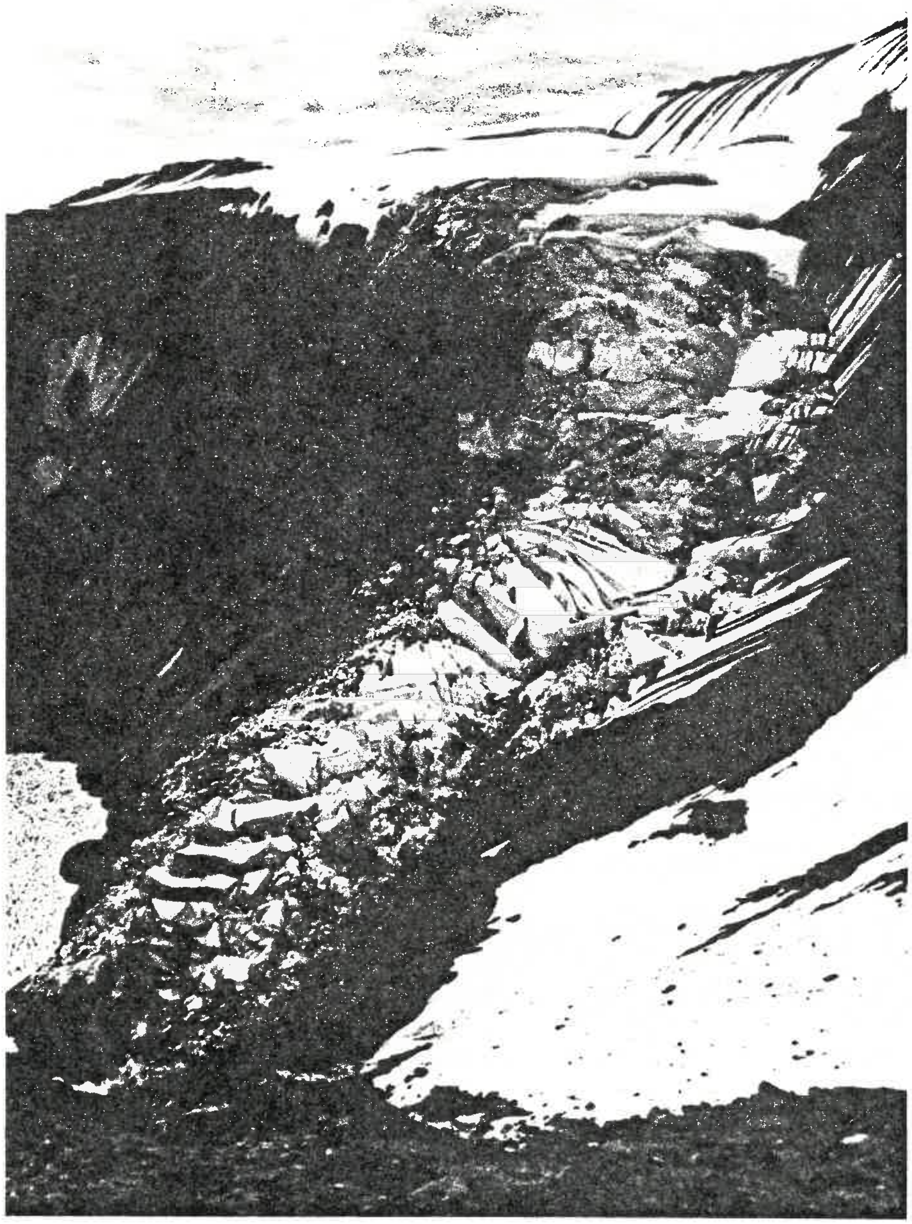


Figure 3. West intra-caldera glacier after surge, Katmai Caldera, August, 1977.

actively calving into the volcanic lake. Lack of snow filling in the crevasses indicates the surge took place in late spring or early summer of 1977.

The cause of glacier surges is not well understood and is a subject of much study and debate. For temperature glaciers* it is generally thought that surges are related to the sliding mechanism in glacier flow. Based on this conclusion the most likely factors contributing to the West Glacier surge are the steepness of slope (25°-30°) and the relatively greater amount of meltwater available from the high precipitation of 1977; both factors would enhance glaciers sliding. The volcanic lake may have also influenced the surge by providing a free floating, frictionless surface at the terminal end of the glacier allowing unhindered advance. As is the case with all glacier surges, an overall decrease in ice mass will result because of the transference of ice from a zone of accumulation or low ablation to a zone of high ablation.

Although no increase in icebergs from the other two intra-caldera glaciers was noticeable during the August 1977 observations, the rise in lake level has nevertheless probably caused an increase in ablation at their terminal ends. The contribution to the lake from glacier ice melt at the termini is considered to be much too small volumetrically to account for the increased rate of lake level rise.

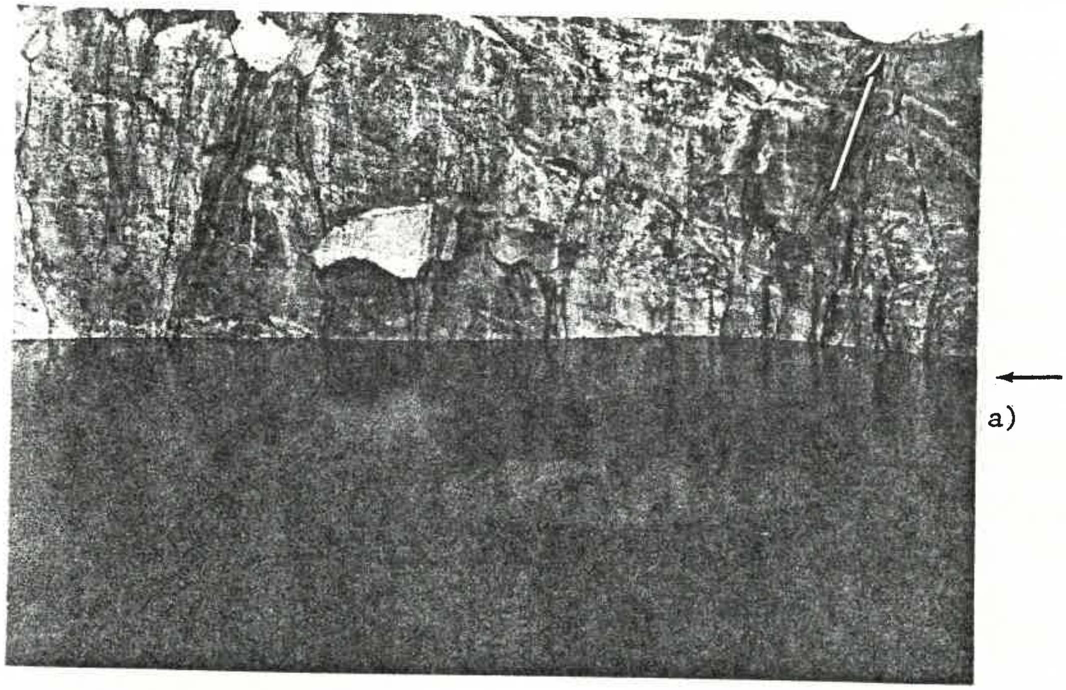
Geothermal Activity: A 100-200 m diameter zone of upwelling was observed in the north-central part of the crater lake in 1974 and 1975 (Motyka, 1977; Motyka and others, 1977); this zone appears to overlie the mud geyser described by Fenner (1930). During 1977 its areal extent was at least twice as great and a new, similar but smaller zone of upwelling was

*Temperate glaciers are glaciers which are at the melting point at their base and throughout most of their thickness. The intra-caldera glaciers are considered to be temperate.

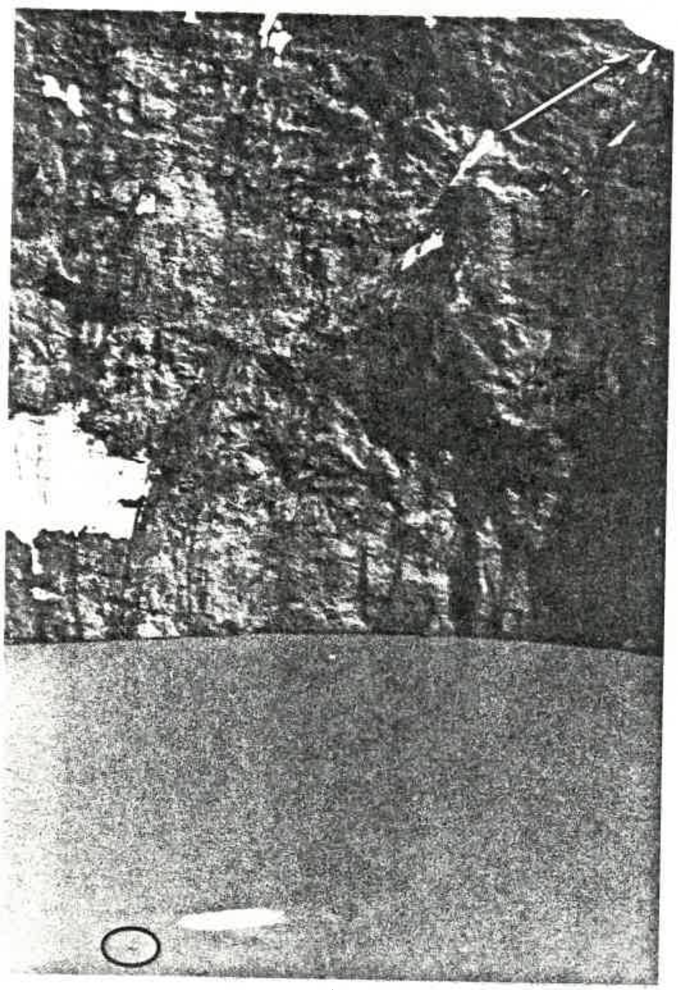
observed in the west-central region of the volcanic lake (Figures 2 and 4). The increased upwelling and an overall increase in sulfur and turbidity in the lake, which is readily apparent in the photos of figure 4, indicate a possible increase in geothermal activity.

Lake temperatures were measured with a calibrated thermistor at several depths near the larger zone of upwelling; the temperature profile is shown in Figure 5. Comparison of the lake-bottom sediment temperature of 20.5°C to similar but more detailed and elaborate measurements made in geothermal areas of Yellowstone Lake (Morgan and others, 1977) indicates a heat flux on the order of 5,000 mW m^{-2} (100 μ cal cm^{-2} sec^{-1}) at this point. The water temperature decreased rapidly above the bottom, falling over 8°C in 10 meters; from 150 m to 10 m, the temperature remained nearly constant, rising only 0.2°C. Near the surface the temperature rapidly increased again under the combined influence of solar and atmospheric heating.

The average temperature of 8.8°C in the upper part of the water column (50 m - 10 m) on 22 August 1977 was significantly higher than the 5.5°C measured in this depth range on 5 July 1975 (Motyka, 1977). Part of the difference could be attributed to the longer summer heat budget prior to measurement in 1977 vs. 1975, though the cooling effect of the larger volume of melt water input in 1977 would tend to offset this to some degree. An alternative explanation for the difference lies in the inherent variance in temperatures and flow pattern present in any large scale convection. Of course, another possible explanation is that sub-lacustrine geothermal heating has increased. Unfortunately, deteriorating weather conditions prevented any additional temperature measurements at other locations.



a) August, 1974



b) July, 1975

c) August, 1977

Figure 4. Zone of Upwelling, Katmai Crater Lake. Photos are of differing scales. Arrow points to common feature. Yellow Raft (circled) in lower left corner of b) is 3 m long.

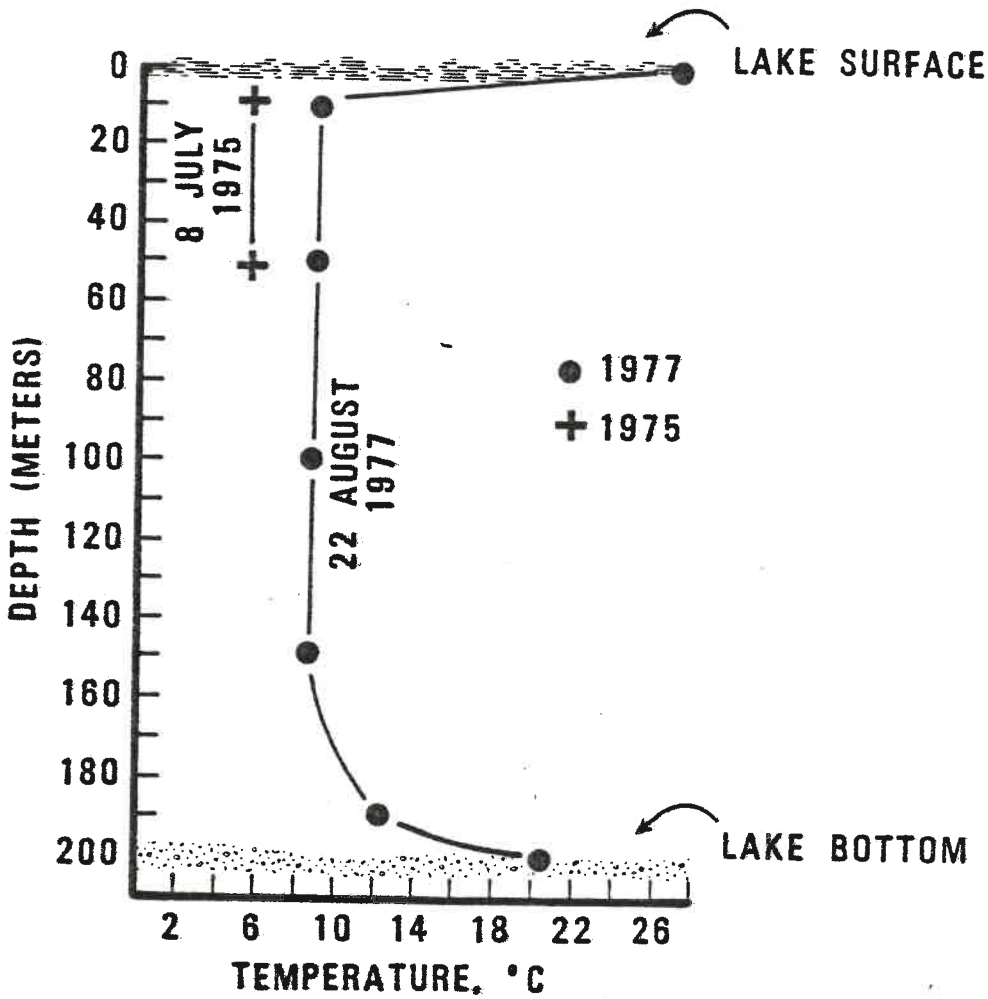


Figure 5. Katmai Crater Lake temperature profile near zone of upwelling, 8 August 1977 and 8 July 1975.

Observations on other Volcanoes: Mt. Mageik appeared to be steaming more heavily in 1977 than in 1975. Furthermore, dirt and ash overlying the snow cover in the vicinity of the active vent was more widespread in 1977 than in 1975. Discretion must be used, however, in interpreting these signs as indicators of increased geothermal activity at Mt. Mageik since atmospheric conditions and weather patterns could easily account for the observed differences. However, analysis of earthquake data discussed below lends support to possible increases in the level of activity at Mt. Mageik.[†]

Earthquake Activity: Analysis of seismic records obtained from the recently completed Geophysical Institute, University of Alaska, lower Cook Inlet-Shelikoff Straits seismic network, shows a concentration of shallow earthquakes (0-25 km deep) centered near Mt. Martin and Mt. Mageik (Gedney and others, 1977; Gedney, 1978) and a large swarming of shallow earthquakes in the vicinity of Mt. Katmai (Gedney, 1978*). These earthquakes may be related to the volcanoes, though position accuracy of the earthquake centers is poor (probably no better than 20 km) because no active seismic station at present exists in this region of Katmai National Monument.

[†]David Johnston of USGS, Menlo Park, climbed Mageik during the summer of 1978 and found the crater lake there to be actively bubbling and blue and yellow in color. Water pH was 1 and water temperature was +70°C.

*Data from some stations operated by the National Oceanic and Atmospheric Administration (NOAA) and by the U.S. Geological Survey (USGS) were also used in the analysis.

Elsewhere in the monument, a number of shallow earthquakes have occurred in the vicinity of Four-Peaked Mountain and Mt. Douglas, both of which are located near Cape Douglas (Figure 1). Location of these earthquakes is considered to be more accurate (∿10 km) owing to the proximity of several seismic stations in the Cape Douglas area.

RECOMMENDATIONS

Given the possible increase in geothermal activity at Katmai Caldera and Crater Lake and the frequency of shallow earthquakes in the immediate vicinity of the volcanoes, continued surveillance of the region is strongly recommended. The following are some specific suggestions concerning what might be done to strengthen the surveillance program.

1. The National Park Service should initiate and maintain as part of its normal operation a periodic reconnaissance of volcanoes in the immediate vicinity of the Valley of Ten Thousand Smokes (Figure 1: Mts. Griggs*, Katmai, Trident, Mageik, and Martin). These volcanoes are the most apt to be visited by hikers or viewed by tourists and pose the most serious threat to life in the event of an eruption. The reconnaissance would probably be best accomplished aerially with photos taken and placed on file together with any notes on abnormal activity. Such a reconnaissance could be done in cooperation with the Geophysical Institute. In any case the Geophysical Institute should be alerted in the event of any large-scale increases in activity.

*Labeled Knife Peak on map.

2. Ground based observations made by park service rangers, particularly someone with a background in the earth sciences would also be beneficial. This would be particularly valuable for monitoring changes in Katmai Crater Lake and intra-caldera glaciers. Rangers could be briefed by Geophysical Institute staff via telephone regarding observations to make and location of points from which photos should be taken. A descent to lake level should not be attempted by any except those soundly trained in safe-mountaineering practices.

3. Because of their invaluable experience and knowledge of the Katmai volcanoes, continued periodic visits by Geophysical Institute scientists is strongly recommended. The frequency of such visits would depend on circumstances and level of geothermal or volcanic activity. More and better crater lake depth soundings are required to help clear-up discrepancies regarding lake depth. Temperature measurements and geochemistry should be continued as a check on increasing geothermal activity. Also important is whether increasing lake level height might trigger surges in the other intra-caldera glaciers.

4. A conspicuous gap occurs in the seismic network coverage between Cape Douglas and Puale Bay. Since this region represents a critical area in terms of volcanic activity, a concerted effort should be undertaken by the various agencies interested in monitoring earthquake activity (NOAA; USGS; Geophysical Institute, University of Alaska; and US NPS) to install, operate, and maintain a seismic station within the vicinity of Mt. Katmai or Mt. Mageik.

At present there is an inactive seismic station located on the Buttress Range adjacent to Lethe Valley (Figure 1). This station should either be reactivated at its present site or moved to a location better suited to monitoring earthquakes and transmitting data. Such a station would be of particular benefit to the US NPS as it would provide a means of alerting the park service to possible eruptive activity.

5. Efforts should be made to integrate scientific findings on the volcanoes into interpretative programs for monument visitors. The volcanoes were the prime reason for the creation of the monument and remain as one of its most significant attractions. Educational programs about the volcanoes of Katmai will help the general public become more aware of the large scale forces of nature that are constantly at work.

CONCLUSIONS

In light of the possible increase in geothermal activity observed at Katmai Crater Lake, the high frequency of shallow earthquakes in the immediate vicinity of the Katmai Volcanoes, and the importance of the hydrologic-glaciologic studies, continued surveillance of Katmai Caldera and Crater Lake and other volcanoes is strongly recommended. The area is well-known for its high level of volcanic activity: several geothermal vents are active within the region and several eruptions have occurred within the monument since its inception. With increased visitor usage of the monument, potentially hazardous conditions from volcanic eruptions could rapidly develop. Of particular importance is the establishment of a seismic station in the vicinity of Mt. Katmai or Mt. Mageik which would help in alerting the park service to possible eruptive activity.

The cooperative project undertaken by the US NPS and the Geophysical Institute, University of Alaska has also provided a unique opportunity to study a rare interaction between free water, volcanic heat, and glaciers. This interaction between the volcanic crater lake and the glacier system is unique in the world and deserves continued observation.

ACKNOWLEDGEMENTS

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