print showing the faintest luminous features is the small extensions of the spiral arms out beyond the burned-out oval of the main body of M81. They trace back to join the main spiral arms tangentially. In other words, the brighter spiral arms lie only inside these outer radii and lag behind (opposite to the inferred direction of rotation) the faint, leading arms. Since the bright arm consists of very young stars, and older stars in our own galaxy lag behind these arms (*4*), the implication is that this very faint leading arm in M81 consists of a larger percentage of even younger but fainter material (that is, a greater percentage of *pre*-stellar material).

How the character of the spiral galaxy changes on the photographs which register the faintest surface brightnesses is also of interest. The interarm region fills in, an indication that there is some luminous material in the general disk. The system grows from one having a diameter of a little more than 15 kpc on ordinary photographs to one that is almost 30 kpc in diameter on the composite photograph.

In summary, it seems that by a stroke of good fortune a relatively nearby spiral galaxy has been recently subjected to a very unusual outside perturbation. By studying the effects of the M82 explosion on M81 we can learn a good deal about a normal spiral galaxy. We can also hope to learn more about the intriguing and powerful explosion that took place in the neighboring peculiar galaxy. Because synchrotron radiation should be strongly polarized, optical polarization plates have been taken, and their study should yield further information on the ring. Detailed radio mapping of the region would also be extremely valuable to check on the synchrotron radiation hypothesis and to obtain an accurate estimate of the total energy radiated by the ring over all wavelengths.

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15 March 1965

Photometry at Cerro Tololo, Chile: Effects of Mount Agung Eruption

Abstract. *Extinction effects of the volcanic dust injected into the stratosphere by the violent eruption of Mount Agung, Bali, 17 March 1963, were studied. Visual extinction coefficients were measured photoelectrically for 153 nights during the period from March 1963 to September 1964. The data indicate that the dust is now widely dispersed and that its effects may persist for several more years. A study of the wavelength dependence of the extinction shows that the dust is a neutral scattering agent. The total global amount of airborne volcanic material is crudely estimated at* 10^{12} *grams as of September 1964.*

Moreno and Stock (*1*) reported on the greatly increased atmospheric extinction on Cerro Tololo, which could be attributed to volcanic ash in the stratosphere deriving from the Mount Agung eruption of 17 March 1963; they gave photoelectrically measured visual extinction coefficients for the period from March to November 1963. Our work extends these observations through September 1964 and also examines the wavelength dependence of the excess extinction. All observations were made with a 16-inch (40-cm) reflector.

The coefficients for 153 nights are plotted in Fig. 1. Most of the gaps in the data result from either cloudy periods, nights with insufficient observations, or the use of equipment that did not permit an extinction determination.

About 50 days after the eruption on Bali (115°E, 8°S) the arrival of a dust cloud over Cerro Tololo (71°W, 30°S) was detected by a sharp rise in the visual extinction from the normal 0.125 to about 0.32 magnitude. A subsequent decline of 0.08 magnitude indicated that the cloud still contained a central condensation at that time. There followed a gradual increase until late September 1963, when the coefficient peaked slightly above 0.4 magnitude. Since that time a slow decline has indicated that the preeruption atmospheric conditions may be restored after several years.

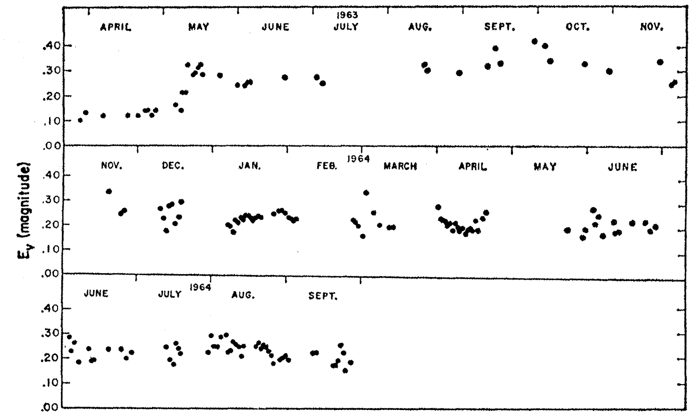
The dust has now dispersed over a wide range of latitude. Its initial appearance at Tucson, Arizona (32°N), has been described by Meinel and Meinel (*2*), who derived an altitude of 22 km for the upper extent of the main concentration. A faint secondary layer at 53 km was also reported. From visual observations made on Cerro Tololo, Stock reports that the horizontal visibility has not been affected. Also, the twilight phenomena produced by the dust seem unchanged when observed from aircraft near 10-km altitudes. Thus most of the material is probably confined between heights of 10 and 20 km, although, as Meinel and Meinel have suggested, some of it must have been injected into the mesosphere.

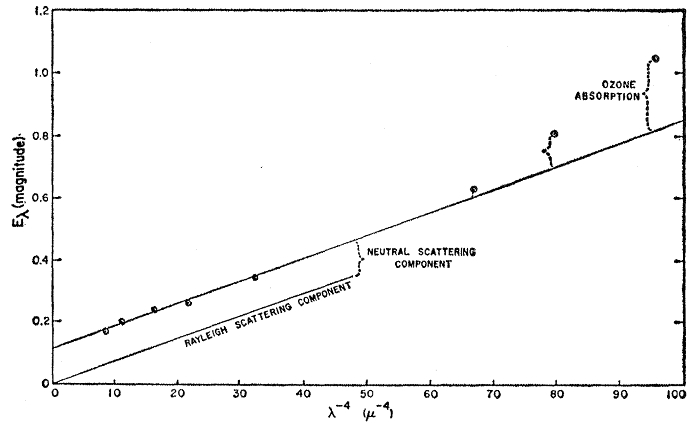
Mossop (*3*) has studied the nature of this volcanic dust from samples gathered during U-2 flights at 20-km altitude. The last reported sample, taken on 7 April 1964 (145°E, 43°S), showed a concentration of 35 volcanic dust particles per liter; the particles had a median size of 0.2 μ. When collected, the particles were heavily coated with a water-soluble material thought to be sulfuric acid. Judged from the particle sample shown by Mossop (*3*, fig. 7), the median radius of these composite particles is several microns.

Because of the large size of the composite particles compared to the wavelengths of visible light, one would expect the excess extinction to be neutral. As such it would present no serious problem for those phases of photometry concerned only with color indices. However, a precise magnitude measurement is impossible under current conditions if one fails to measure accurately the extinction each night. The short-period fluctuations (Fig. 1) are large compared with the night-to-night variations observed prior to the eruption and with errors in the observations (probable error < 0.01 magnitude). The fluctuations indicate that the dust has a patchy distribution; this condition makes it impossible to define a mean extinction coefficient for magnitudes that would be valid for even a few consecutive nights.

A photoelectric scanner (*4*) was used to study the wavelength dependence of the extinction. During the nights of 11, 12, and 20 September 1964, the extinction was measured at the following eight wavelengths that were chosen to avoid disturbing effects of absorption features in the stellar spectra: λ3200, λ3350, λ3500, λ4200, λ4650, λ5000, λ5500, λ5900 Å. The slit width was about 80 Å.

The results for the three nights were combined (Fig. 2, curve *A*). Unfortunately, no corresponding preeruption





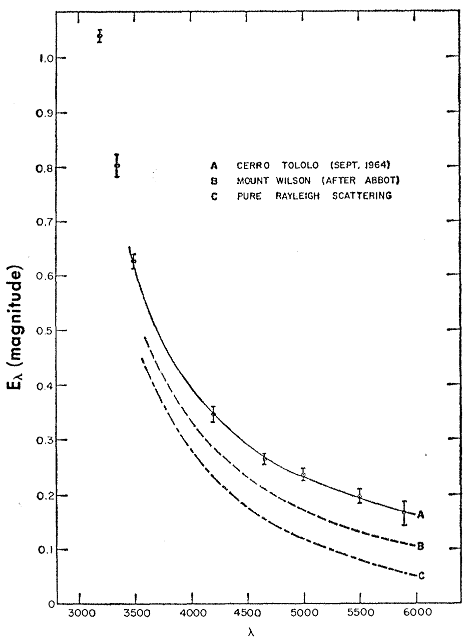


Fig. 1 (upper left). Variation in the visual extinction on Cerro Tololo during 1963–64.

Fig. 2 (left). Comparison of the wavelength dependence of the extinction on Cerro Tololo during September 1964 with conditions on Mount Wilson and with the case of pure Rayleigh scattering.

Fig. 3 (upper right). A plot of the extinction observations versus λ^{-4}, showing the three principal components of the extinction.

curve is available for Cerro Tololo. We can, however, make a comparison with data obtained by Abbot (*5*) at at Mount Wilson (curve *B*), and with the theoretical Rayleigh scattering in an atmosphere of pure air with a reduced height of 5.9 km (curve *C*); the latter figure is based on Cerro Tololo's elevation of about 2195 m.

Within the accuracy possible with this method, curve *A* was found to be systematically elevated above curves *B* and *C* by 0.06 and 0.11 magnitude respectively. This result verifies the neutral action of the dust.

In Fig. 3, this conclusion is reinforced by a plot of the extinction observations versus λ^{-4}; pure Rayleigh scattering is represented by the lower line passing through the origin. We point out the divergence from linearity shown by the observations at λ3200 and λ3350. This departure is caused by ozone absorption, which first becomes noticeable at λ3500 and increases rapidly with decreasing wavelength. The observed ozone-absorption coefficient is 0.20 at λ3200 and 0.09 at λ3350. According to Allen (*6*), these values are consistent with a total ozone layer of 2.3 mm at normal temperature and pressure.

Combining the information in Fig. 2 with the preeruption value of the visual extinction coefficient of 0.125 magnitude, we draw the following conclusions. The normal dust and haze above Cerro Tololo cause about 0.045 magnitude of visual extinction. This value is comparable with the value obtained during the best conditions that prevailed on Mount Wilson when Abbot made his observations. As of September 1964, the volcanic dust was contributing an average of an additional 0.07 magnitude of neutral extinction at Cerro Tololo, and presumably a comparable amount over much of the globe. The widespread dispersion in latitude of the dust may have helped to cause the extremely dark lunar eclipse observed on 30 December 1963.

From this known amount of excess extinction, one can roughly estimate the total amount of volcanic material aloft at the time of our observations. The particle concentration is expected to vary with altitude. However, using Mossop's results and the known altitude variation of the concentration and size of aerosols normally in the atmosphere, we can estimate the mean concentration at about 100 volcanic particles per liter over the altitude range from 10 km to 20 km. If these were nearly spherical particles with a radius of 3 μ, they could account for the observed 0.07 magnitude of extinction. We then assume that each of these coated particles has as its nucleus a dust particle with a 1-μ radius and a density of 3 g/cm^3. The total mass contained within an atmospheric column of 1-cm^2 cross-sectionial area is then about 10^{-6} g. The total amount of material covering the latitude range from 45°S to 45°N would be about 10^{12} g or the equivalent of 3×10^5 m^3. No estimate is available for the overall amount of material ejected during the eruption. An estimate of

6×10^9 m^3 of ejected material was made in the case of the eruption of Krakatoa in 1883 (*7*). Thus, even if the Mount Agung eruption involved 100 times less material than Krakatoa, the amount of airborne dust would still represent only about 1 percent of the total amount ejected.

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Alaskan Glaciers: Recent Observations in Respect to the Earthquake-Advance Theory

Abstract. *Preliminary aerial photographic studies indicate that the Alaskan earthquake produced some rockfalls but no significant snow and ice avalanches on glaciers. No rapid, short-lived glacier advances (surges) are conclusively associated with this earthquake. Recent evidence fails to support the earthquake-advance theory of Tarr and Martin.*

After a series of strong earthquakes centered near Yakutat Bay, Alaska, in 1898, Tarr and Martin (*1*) reported nine glaciers which made short-lived, rapid advances (surges) (*2*). They proposed that ice and snow, shaken from the mountains in the upper regions of the glaciers, had caused a "flood" wave and that this wave traveled from source to terminus in periods of less than 1 year to 11 years, the delay being dependent upon the length of each glacier. Despite the fact that few observations were made in the upper portions of the glaciers where the avalanching was supposed to have occurred, the earthquake-advance theory has gained widespread acceptance.

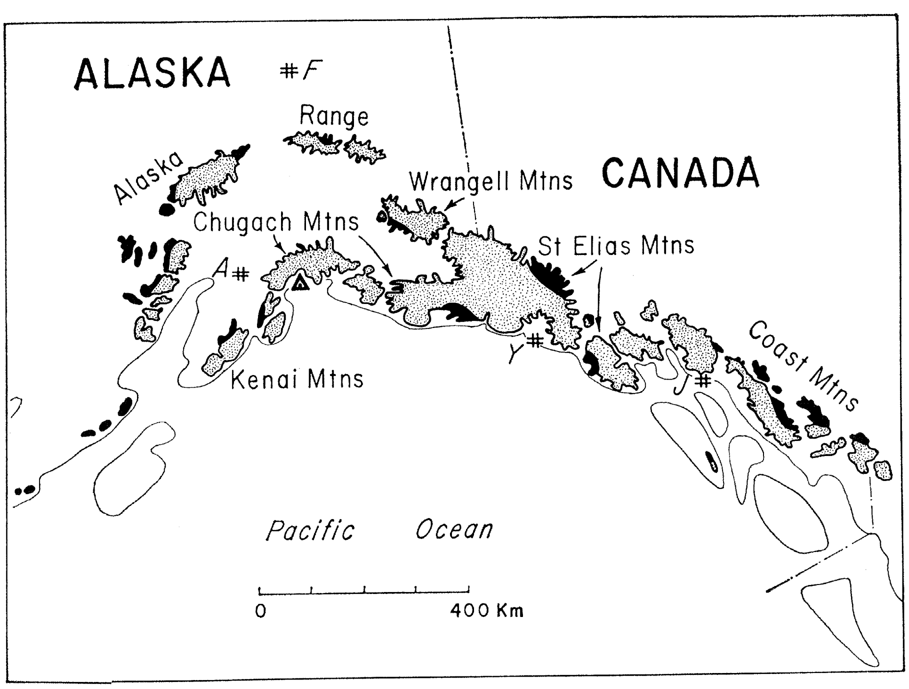

Fig. 1. Locations of major glacierized areas in south-central Alaska. Dotted areas were visually examined and the major features photographed in 1964; black areas represent glacierized regions not observed in 1964. Cities or towns: *F*, Fairbanks; *A*, Anchorage; *Y*, Yakutat; *J*, Juneau. Epicenter of 1964 earthquake indicated by triangle.

The epicenter of the Alaska earthquake of 27 March 1964 (magnitude 8.4 to 8.6) (*3*) occurred in the heavily glaciated Chugach Mountains (Fig. 1). Thirty-eight glaciers over 20 km in length and many hundreds of smaller glaciers exist in the region where the shaking was most intense. This is an area ideally situated to provide evidence which might verify the theory of Tarr and Martin. Observations in 1964 permit an immediate test of Tarr and Martin's theory in that (i) if extensive snow and ice avalanching did occur it should be readily observable, and (ii) if the earthquake caused any abrupt surging as described by Tarr and Martin the beginning stages of it in the higher reaches of the glacier should now be sufficiently developed to be detectable. The situation has, therefore, attracted the attention of many glaciologists and geologists (*4, 5*).

In 1960, 1961, 1963, and 1964, I made aerial examinations of nearly all of the glaciers in Alaska and western Canada (Fig. 1), by visual inspection and with vertical and oblique photography. More than 500 large glaciers and several thousand smaller ones were observed in late summer during the course of each study. Therefore any changes in nearly all of the more prominent glaciers could be analyzed. The following features were given careful attention: evidence of avalanching (snow, ice, or rock), position of the glacier terminus, the amount of crevassing which might denote changes in the rate of flow, evidence of changes in the surface levels of the ice both in the accumulation and ablation areas, movement and deformation of surface features such as medial moraines, changes in the marginal streams and lakes in ice-blocked valleys, and evidence of changes in glacier surface drainage and outlet streams.

The results of this study are clear. The earthquake had little visible immediate effect on the glaciers, except for some localized rockfalls. Practically no changes in terminus configurations, drainage patterns, surface levels, or glacier activity were observed which might not have occurred in these glaciers in any normal year. The examinations in 1964 in other areas and photography taken in previous years provide satisfactory bases for comparison. Evidence of significant snow and ice avalanching even on very steep slopes was not found during the August observations. Minor snow and ice avalanches had occurred in all