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THE MOVEMENT AND DISPERSION OF VOLCANIC DUST FROM THE ERUPTION OF MT. AGUNG, BALI, 17 MARCH 1963

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INTRODUCTION

The possibility of tracing large scale stratospheric motions and diffusion presented itself when great quantities of fine volcanic matter were ejected to high altitudes by the eruption of the Bali volcano on 17th March 1963.

In the past, eruptions of this magnitude were usually followed by reports of unusually vivid sunrises and sunsets and hazy conditions. The great eruption of Krakatoa in August 1883 in which two-thirds of the island was blown away, ejected such enormous quantities of finely pulverised matter into the atmosphere that appreciable quantities remained aloft for more than three years, producing many brilliant sunsets and sunrises and other phenomena of light refraction such as Bishop's Rings. Similar phenomena were reported over most of the Australian continent following the eruption of Mount Agung, and this brief study of the movement and dispersion of the volcanic particles over the continent was based on an analysis of these reports.

DISCUSSION

After examining field books from all meteorological stations over the continent, newspaper reports and public correspondence, and noting any reports of unusual atmospheric effects, the dates of first sightings of unusually brilliant sunsets or high level dust clouds were mapped. Isochrones of these dates indicated a well-defined pattern of dispersion of the particulate matter (See Fig. 1).

The dates that brilliant conditions were first noticed were not always a true indication of the actual date of reception of the volcanic dust cloud, as cloud conditions had to be taken into consideration, and data from stations experiencing overcast conditions for some days prior to their first report of vivid sunset were disregarded.

Two of the earlier reports of high level dust cloud occurred on 21st March 1963, four days after the initial eruption, at Broome (17°57'S 122°13'E) and Halls Creek (18°14'S 127°40'E). Halls Creek reported unusually brilliant sunsets from 21st March and a very high cirrostratus-like cloud in bands was first observed on 23rd March. This high altitude cloud was visible for about fifteen minutes around every sunset and sunrise, but not during the day. Sunsets intensified in brilliance on 20th May. Broome reported this same cloud and vivid conditions commencing March 21st and continuing for almost two weeks, with a recurrence of brilliance from 29th May. Port Hedland on the other hand reported sighting of the dust cloud on 31st March but did not report brilliance of sunset until 3rd April. The high altitude dust was described as having the appearance of a very high layer of uniform cirrus, estimated at 45,000 ft, with a clearly defined leading edge and lying ENE to WSW on the date of first sighting. This cloud increased, according to the report, from one octa on the morning of the 31st to four octas in the afternoon of the same day, then gradually increasing to eight octas on 2nd April or taking up to two and a half days to traverse from horizon to horizon. Vivid reflection then began to occur with maximum brilliance 35 to 45 minutes before sunrise and after sunset. Brilliance was reported to persist for up to two hours. On 18th May upper haze and strange high level cirrus were again sighted.

There were two eruptions of the Bali volcano, the first on 17th March 1963 and a second two months later on 16th May. Whether the second cloud sightings and reports of resumed brilliance by some stations can be attributed to the arrival of particulate matter ejected by the latter eruption, or to dust re-appearing after global circuit, is difficult to establish. In this study only sightings of dust concentrations that can be attributed with some degree of confidence to the first ejection will be taken into consideration, as reports indicate the Bali volcano also continued to eject matter from time to time during the intervening period between the two main eruptions.

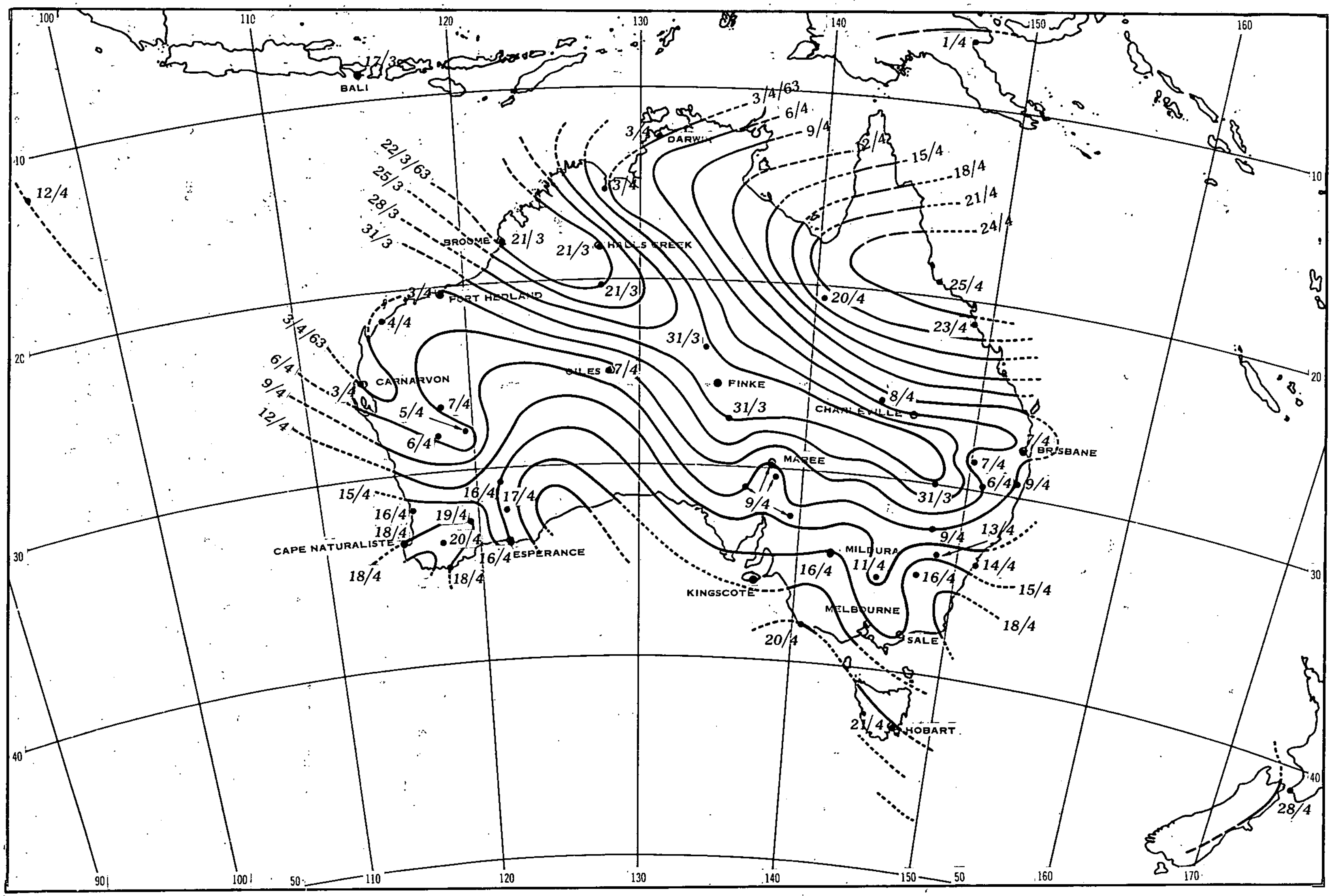

Fig. I Map of Australasian region with isochrones, at three-day intervals, of first reports of optical phenomena attributed to high altitude volcanic dust ejected by the Mt. Agung eruption of 17 March 1963.

An interesting feature was the lapse of two days or so, in the main, between the report of the first vivid sunset and the report of first vivid sunrise, again indicating the very slow transmigration of the dust particles causing the phenomena.

Figure 1 shows the horizontal dispersion of the particulate matter in two main 'tongues', the main 'tongue' taking about twenty days to traverse the continent in a diagonal trajectory from Broome on the north-west coast to Brisbane on the east coast, and a secondary 'tongue' arriving over Carnarvon on 3rd April and reaching Esperance on 16th April, thirteen days later.

The isochrones of Fig. 1 indicate an average lateral dispersion in the horizontal of only about one knot and an average forward dispersion in the main 'tongue' of about 3 knots.

As there were many conflicting estimates of the altitude of the main dust concentration, an inspection of the upper wind soundings for the period of its transit was carried out. It was apparent that wind speeds at the estimated altitudes of the dust were greater than the speed of the dust based on the time lapse between sightings from station to station, although in the main the wind directions corresponded to the direction of dispersion of particulate matter indicated by the isochrones. The available soundings indicated a change from westerlies in the lower levels to easterlies in the higher, with a layer of relative calm at changeover level, and suggested the probability of the particles being suspended within this region of directional change. This seemed to be the only plausible explanation of its slow migration.

Returning to the map of first sightings, an examination of the upper winds at each station on the date interpolated from the isochrones of Fig. 1 was conducted. The altitudes at which the directional change in wind was complementary to the direction of the horizontal dispersion of particulate matter indicated by the isochrones of Fig. 1 were then plotted against each corresponding station (Fig. 2). Unfortunately, in some cases wind soundings taken on the interpolated dates were of insufficient altitude. In these cases average heights of the level of relative calm up to five days prior to and after the interpolated dates, were used. Fig. 2 suggests that if the assumption in the previous paragraph is correct, the altitude of the main layer of dust must have increased with its southerly migration as the height of the change of wind direction varied from about 14 km over Broome to 19 km over Giles, 22 km over Mildura, 24 km over Melbourne, and 27 km over Hobart, almost doubling its altitude in its migration from Broome to Hobart. Fig. 2 is also compatible with the general pattern of dispersion suggested by the isochrones of Fig. 1.

Several probes by U-2 aircraft of the U.S. Air Force were made over Australia, during the period of transport of the volcanic dust cloud, in an experiment for the detection of intrusion of extra-terrestrial matter into our atmosphere. Mossop (1964) has reported that an aircraft from Sale travelling north on 11th April along longitude 145°E, from 35°S to 15°S, on a level flight at 20 km altitude, collected particles of an entirely different appearance from that attributed to extra-terrestrial origin. These were realized to be of volcanic origin as the date of collection coincided with reports of vivid sunsets. Another flight at 20 km on April 23rd, this time travelling south along longitude 145°E, collected only the larger of the southward diffusing particles between latitudes 39°S and 42°S.

Stokes' Law defines the rate of fall of small particles in air from great heights under the influence of gravity as:

$$\text{Rate of fall (ft/hr)} = 0.35\,\rho d^2$$

Where ρ = density of particle in grams/cm^3
d = diameter of particle in microns (μ)
(1 micron = 10^{-6} metre)

Thus the larger particles (particles of diameter 8μ were collected during the U-2 experiment) would have a descent rate of much greater magnitude than the finer, more buoyant particles, which would have to contend with atmospheric turbulence and Brownian Motion (rate of fall affected by collision with air molecules).

This would place the particles of greater dimension at the base of the dust layer, releasing them by order of greatest diameter into the westerlies, underlying the layer of relative calm in which the main concentration of dust particles was suspended. In this case dust haze would have been reported some days prior to the date of sighting of the slower travelling high level dust concentration. This in fact was the case, with Charleville (26°25'S 146°17'E) reporting widespread dust six days prior to reception of high level volcanic dust, Kingscote (35°40'S 137°38'E) reporting fine smoky haze nineteen days prior to reception of high level dust, Maree (29°39'S 138°04'E)

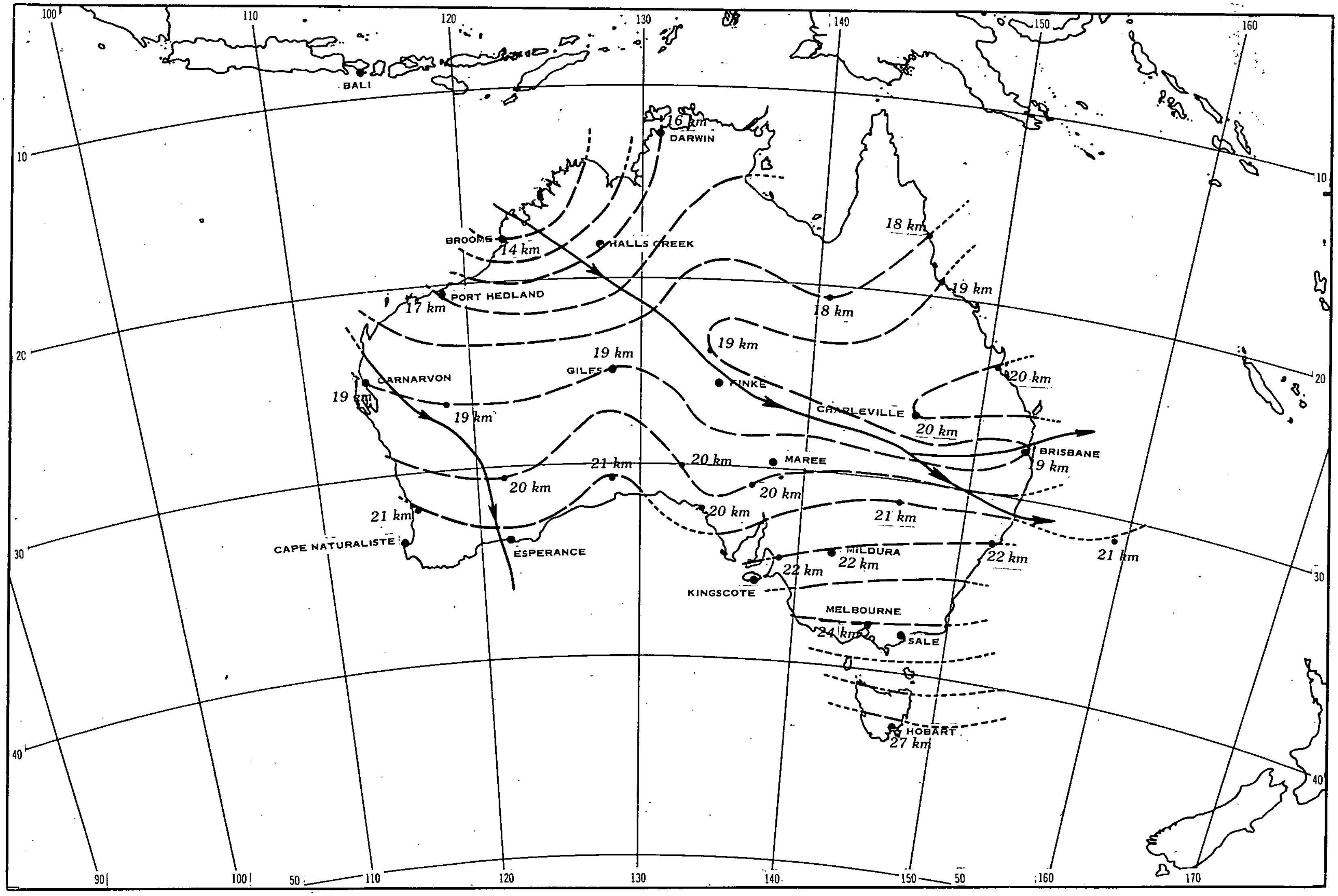

Fig. 2 Map of Australasian region showing approximate altitudes in kilometres (broken lines) at which the change of direction of winds from westerlies to overlying easterlies occurred. The continuous arrowed lines show the migration of volcanic dust at its main 'tongues'.

reporting dust ten days prior, Cape Naturaliste (33°32'S 115°01'E) one day prior, Finke (25°34'S 134°11'E) four days prior and Halls Creek (18°14'S 127°40'E) two days prior. Winds underlying the layer of relative calm were favourable to pre-reception of lower level dust over all these stations. However Giles (25°02'S 128°18'E), which reported low level dust four days after sighting the high level concentration, reported south-westerlies at the level underlying the changeover level, not favourable to pre-reception of low level dust. This agrees with Fig. 1 which suggests retarded motion of the dust cloud over this location.

The U-2 flights also indicated the probability of gradual fallout of the larger particles and ascent of the finer with southerly migration. On 11 April at level flight at 20 km and proceeding from 15°S to 35°S along longitude 145°E, the aircraft would have penetrated a main layer of dust concentrated at the time at about 26°S. It would have collected a high percentage of particles of about 1.0μ, which was the median dimension of particles collected during the overall experiment. It did in fact collect a concentration of 8 particles per litre of mean diameter 1.1μ, maximum diameter 3.6μ and minimum diameter 0.4μ. The flight of 23rd April along longitude 145°E at altitude 20 km and travelling from 39°S to 42°S, discovered a concentration of only 0.7 particles per litre, but of larger median size 2.0μ and of maximum diameter 6.0μ and minimum diameter 0.6μ. The high level concentration of dust was spread well over these latitudes by this date.

The explanation is that although the first northerly flight actually penetrated the main dust concentration at 20 km, the southerly flight underpassed the main layer, indicated at altitudes above 24 km by Fig. 2, and collected only the larger descending particles as they fed through the base of the main dust layer which was ascending.

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REFERENCE

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