Table 1. Relative frequency of color forms and population density in four populations of *Limicolaria martensiana*.

Density per m²	Percentage			
	Streaked	Pallid 1	Pallid 2	Pallid 3
	Makerere (N = 1594)			
>100*	61.4	16.2	19.2	2.7
	Kagugbe (N = 3455)			
15.3†	68.4	15.2	12.9	3.5
	Kitante (N = 428)			
8.0‡	80.0	10.0	10.0	
	Kololo (N = 382)			
<1§	100.0			

* Snails in enormous concentrations over 20 m²; total population not greater than 5000 (other populations greater than 10,000). † s = 10.0. ‡ s = 2.8. § A garden population with overall density less than 1 per m², but local concentrations of up to 6 per m².

Kagugbe all three occur and together comprise 31.6 percent of the population. The 7 percent difference between Makerere and Kagugbe is statistically significant ($\chi^2_{(1)} = 23.95$, $P < 0.001$). At Kitante the rarest of the pallid forms (pallid 3) is absent and the other two together comprise 20 percent of the population. As shown in Table 1, the highest relative frequency of pallid snails occurs at Makerere, where the population density is highest. In the other populations there is a decrease in the relative frequency of pallid snails with lower population densities, and at Kololo pallid snails are absent.

One explanation of these figures is that more different genotypes can exist in an area favorable to a species than in a less favorable area. But in view of the striking differences between the streaked and unstreaked snails I suggest the following alternative explanation: To the human eye the streaked form of *L. martensiana* appears cryptically colored; the intricate pattern makes this form difficult to see in natural situations, especially when bright sunlight and deep shade alternate. In contrast, the pallid forms do not appear cryptic, indeed they often seem very conspicuous. There is evidence that a great many predators, both vertebrate and invertebrate, eat the snails.

It is possible that polymorphism in populations of *L. martensiana* is maintained by what has been termed "apostatic selection" (*2*) in which the selective advantage of two or more sympatric and contrasting color forms lies in their conspicuous difference from each other. In theory, predators that use past experience as a guide in finding a particular prey find proportionately more of a color form with which they have already had significant success. Hence color forms that stand out from the "normal" cryptic form would be at a selective advantage. Further, it may be supposed that predators would be more able to develop a specific search image when the population density of the prey is high than when it is low. In *L. martensiana*, the streaked form may be at a selective advantage because of its cryptic coloration so long as the density of the population is not above a certain critical level, at which point contrasting noncryptic forms may assume an advantage. Hence the resulting equilibrium between color forms maintained by apostatic selection should depend, at least partly, upon the density of the population. The figures given in Table 1 support this view.

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2. B. Clarke, *Systematics Association Publication (London)* No. 4, 47 (1962); G. B. Moment, *Science*, **136**, 262 (1962), uses the term "reflexive selection" which has much the same meaning as "apostatic selection." I prefer the word *apostatic* because it suggests that the forms stand out from each other, an important part of the theory here presented.

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Atmospheric Circulation from Fission-Product Radioactivity in Surface Air

Abstract. *The β-activity of fission products in surface air are analyzed in a diagram, with latitude and time as coordinates. Spring-season maxima and spread of new debris are readily discerned. Debris from 1961 Soviet testing, traveling by way of the upper troposphere or the stratosphere, arrived at 16° to 35°S more than a month before debris transported through the troposphere. A maximum lateral-diffusion coefficient of about* 4×10^5 *m² sec⁻¹* *is implied for the tropical troposphere, and a much larger value in middle and high latitudes. Debris in the troposphere from United States testing at 2°N spread mostly into the southern hemisphere.*

Lockhart (*1*) of the U.S. Naval Research Laboratory has for several years published, at monthly intervals, daily and weekly averages of fission-product β-activity in surface air at 13 stations near the 80th meridian (west). From the tabulations of the data, he has plotted monthly averages of fission-product activity against latitude and has from time to time called attention to the appearance at various latitudes of fresh debris from nuclear tests. Lockhart *et al.* (*2*) have also given interpretations based on the latitudinal profiles and radiochemical analyses.

The purpose of this report is to present and interpret in terms of atmospheric circulation an analysis of weekly averages of these fission-product β-activities plotted in a diagram with latitude and time as coordinates for the period from 1 January 1961 through 30 September 1962. This analysis is shown in Fig. 1. It contains in a somewhat different representation all latitudinal profiles and shows at once many properties of atmospheric transport of fission product radioactivity, including rapid stratospheric transport across the equator, drift of U.S. debris into the southern hemisphere, and other significant properties which are not readily deduced from diagrams of monthly averages versus latitude.

In Fig. 1, somewhat irregular intervals of activity have been chosen for contouring because of the extreme range of activities during this period. Weekly averages were plotted for each station, but the plotted values have too high a density to be shown in the diagram. The contour analysis may be regarded as more accurate horizontally at the latitudes of observation, less accurate along any vertical axis, particularly between Moosonee and Thule. It is usually assumed that debris concentrations in surface air, except in the first few weeks after nuclear tests, vary most with latitude and least with longitude. This is supported by the fact that activities at Mauna Loa at 19°28′N, 155°36′W have approximately the same average as activities at San Juan at 18°26′N, 66°00′W. However, these stations have widely different elevations (Mauna Loa, 3394 m; San Juan, 10 m), so that the comparison rests on the assumption of small dependence on elevation. The percentage increase of average activity with elevation within the troposphere seems to be fairly small, judging from various activity soundings which have been presented in the literature. Moreover, data from Chacaltaya at 5220 m were used in the analysis of Fig. 1, where they seem to fit in reasonably well with the data from neighboring stations situated at low altitudes. Data for several stations were missing for various lengths of time, as indicated in the diagram, although the only serious lapse occurs at Guayaquil from April through July 1962, the period just after the resumption of testing by the United States at Christmas Island. Data for San Juan were missing for long periods in 1961, but where data were available, the values compared well with data from Mauna Loa. Hence the Mauna Loa data were used as a guide for analysis of the missing regions.

The letter *F* in the far left-hand side of the diagram indicates the position in latitude and time of a French kiloton-yield nuclear test in the Sahara. Debris from this test appeared briefly along the 80th meridian between 10° and 20°N in early January, as indicated by the small high. The southward drift and quick removal resembled the behavior of debris from a previous French test in February 1960, as may be demonstrated by leftward extension of the diagram. The *F* in late April 1961 denotes another French kiloton-yield test, but neither Lockhart's (*1*) radiochemical analysis nor the analysis of Fig. 1 detected it.

A spring maximum has been noted by Lockhart and other investigators. In 1961 it appears first around 20°N in April, and later with increasing latitude, finally appearing in early June at 45°N. This lag is similar to that which occurred in 1960. Although some activity was added to the lower stratosphere in 1960 and 1961 by kiloton-yield tests, removal from the atmosphere and decay reduced the 1961 maximum to less than half that of 1960. The high which appears between Moosonee and Thule has no counterpart in 1960, and appears to be separate from the usual spring high whose orientation probably results from the movement northward in spring of the disturbances which transfer debris into the troposphere (*3*). This is consistent with the results of Newell (*4*), who has found positive correlation between northward movement of jet streams and surface radioactivity maxima.

Until September 1961, the general pattern in both hemispheres resembles that which may be shown for 1960, except that 1961 activities are expectedly smaller. Then, on 1 September 1961, the Soviet Union resumed testing in the atmosphere with kiloton-yield weapons at 52°N near Semipalatinsk. This was followed at Novaya Zemlya at 75°N on 10 September 1961 by a series that lasted into November and included at least fifteen tests of megaton or greater yield, one of which was the notorious 55-megaton bomb detonated at 12,000 ft on 30 October. Figure 1 shows an abrupt flood of debris in early September from the Semipalatinsk source past the 80th meridian from 25°N to at least 52°N. The analysis at Thule is based on an average activity for 12 through 18 September. Since daily values were not available, we must note that this larger weekly average could have come from Novaya Zemlya as well as Semipalatinsk. Activities increased by a factor of roughly 100 in middle latitudes with the appearance of this debris. The simultaneous onset throughout middle latitudes in contrast to the delayed onset south of 25°N reflects a vastly greater meridional mixing at middle latitudes, mixing so intense that after approximately 10 days and an eastward longitudinal drift of 200 degrees, debris from a point source (or, perhaps more accurately, a vertical line source) has spread through at least 27 degrees of latitude.

Weak meridional mixing equatorward of twenty degrees north or south drastically delays the penetration southward into the southern hemisphere. The fact of transequatorial mixing has of course been noted from radiochemical analysis by Lockhart *et al.* (*2*), by Junge from carbon dioxide and tritiated methane measurements, and by others. The latitude-time section shows rather nicely the speed with which newly introduced tracers penetrate southward. It does not reach the equator until November 1961 or 13°S until January 1962. This is shown by the contours sloping downward from left to right. Radioactive decay and dilution by mixing and tropospheric removal reduce the packing of contours southward, but the first of the packed activity contours must represent the first appearance of Soviet debris. Rough estimates of westerly winds in the troposphere indicate that debris from the first Soviet test circled the globe several times in temperate latitudes during the time required for tropospheric mixing southward from 20°N to 13°S.

From the slope of contours a velocity of transport southward of about 0.7 mi hr^{-1} may be calculated for the region from 10°N to 10°S. It is possible also to make a crude estimate of the maximum horizontal diffusion coefficient by means of $\overline{y^2}\ (t) = 2Kt$, where y^2 is the variance, K is the diffusion coefficient, and t is time. This expression, subject to the assumptions of homogeneous turbulence and large times, gives the displacement variance of a "tagged" particle that is being transported by the atmosphere. By setting $K = \overline{y^2}/2t \sim y\bar{v}/2$, where $\bar{v}$ is the velocity calculated above and y is the distance (20° lat) used in calculating $\bar{v}$, we find $K = 4 \times 10^5$ m^2 sec^{-1}. Phillips (*6*) has shown that a diffusion coefficient of 10^5 m^2 sec^{-1} is appropriate to diffusion by eddies with dimensions less than or equal to 300 km and velocities less than 1 m sec^{-1}. He notes also that 10^5 m^2 sec^{-1} is about 1/40 that necessary to balance the radiative heating loss at higher latitudes. The large scale disturbances outside the tropics should therefore correspond to a diffusion coefficient some 40 times greater than that appropriate to the tropics. The differing rates of meridional spread of radioactivity are certainly consistent with diffusion coefficients differing by a factor of at least 10 between the tropics and the middle and higher latitudes, since the time required for spread of the radioactivity through some 20 degrees of latitude in middle and high latitudes is of the order of 1/10 or less than the time required in the tropics. Of course, northeast trade winds may represent a systematic meridional transfer, and the diffusion coefficient obtained above should probably be regarded as an upper limit.

The earlier appearance of high activity from 16° to 35°S in November and December 1961 suggests a somewhat more rapid meridional transport across low latitudes in the stratosphere or the upper troposphere. These activities exceed those of November and December 1960, whereas, because of decay and removal, lower values would be anticipated. Moreover, Lockhart (*1*) has found small but identifiable quantities of cerium-141 (33 day half-life) as far south as Santiago, Chile, during November and December of 1961 by means of radiochemical analyses of the same filters from which the gross β-activities were obtained. Noting that this isotope had not been detected in the southern hemisphere since spring 1960 after the first French nuclear test, Lockhart concludes that Soviet debris probably had reached Chile by interhemispheric mixing processes after other processes had carried it to lower latitudes of the northern hemisphere. Hence the gross β and the specific

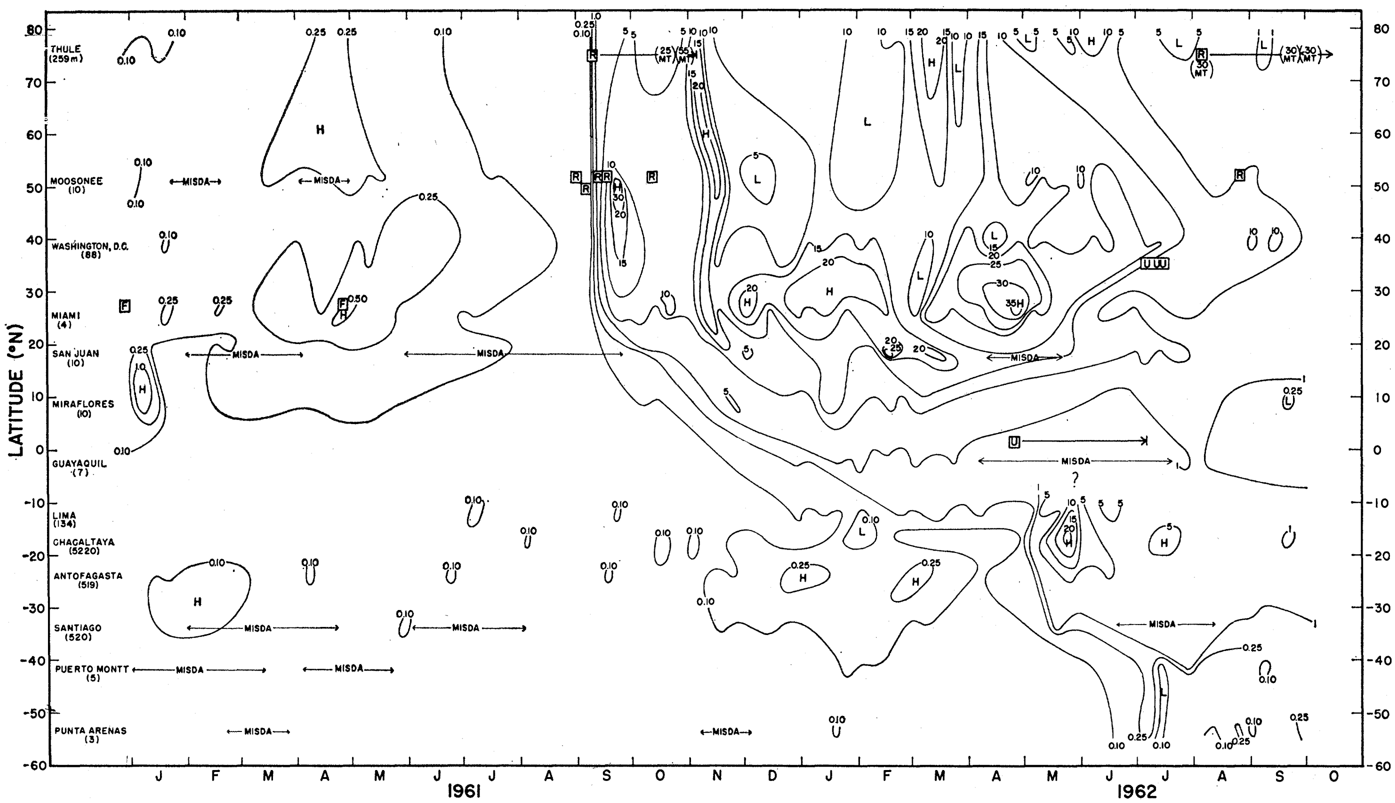

Fig. 1. Concentration of gross β-activities from fission products, expressed in disintegrations per min per m^3 of air at the collecting site, in surface air along the 80th meridian (west) from January 1961 through September 1962 as constructed from data presented by Lockhart (*1*). Observing stations and their elevations in meters are shown at the left. *MISDA*, missing data; *H* and *L*, centers of high and low values; *F*, *R*, and *U*, latitude and time of atmospheric testing by France, the U.S.S.R., and the United States in Algeria near Reganne at (25°N, 1°W), in the U.S.S.R. near Semipalatinsk (52°N, 78°E) and Novaya Zemlya (75°N, 55°E), and either at Christmas Island (2°N, 157°W) or in Nevada (36°N, 115°W), respectively. Arrows extending from these letters denote a test series including numerous weapons of multikiloton and multimegaton yield. Dates with yields in megatons (MT) of the largest detonations are indicated in parentheses.

radiochemical analyses are consistent, and we must conclude that interhemispheric mixing within the upper troposphere or stratosphere was more rapid than within the lower troposphere. Transfer through the lower stratosphere seems more likely, since, if the transfer were by way of the upper troposphere, vertical mixing should have brought some of it into surface air on its way south. A southward velocity of transport within the upper troposphere or stratosphere may also be calculated, although with less certainty. By assuming debris had arrived at 20°N on 15 September, and had arrived at 25°S on 15 November 1961, the velocity of southward transport turns out to be about 2 mi hr^{-1}. The corresponding diffusion coefficient is 10^6 m^2 sec^{-1}, or somewhat larger than for the lower troposphere. A larger mixing in the stratosphere is consistent with inferences by Reed, *et al.* (*7*) that the 26-month oscillation of zonal winds in the equatorial stratosphere requires eddy transport toward the equator of westerly momentum. It may be anticipated that meridional transport in the stratosphere near the equator will vary throughout the year and from year to year.

During the Soviet testing in autumn 1961, the highest activities occurred only slightly to the south of the latitude of testing. These activities probably consisted mostly of debris which entered the troposphere at the time of testing and consisted to a lesser extent of debris which first entered the polar stratosphere and later was transported southward into the troposphere. The 25- and 55-megaton detonations produced an elongated high which extends from Thule southward to Miami in early November. This rapid latitudinal spread resembles that which occurred when testing resumed in September. However, the maximum produced by these super-bombs is slightly less than that of the earlier maximum; presumably a very high percentage of the debris went into the stratosphere. Also, the U.S. Atomic Energy Commission noted on 9 December 1961 that the 55-megaton test had a smaller fission yield.

After termination of test series in November, maximum activities shift farther south to around 30°N and remain there until late spring 1962. If these activities were weighted in proportion to atmospheric mass in narrow latitudinal intervals, the maximum around 30°N would be even more exaggerated compared with higher latitudes. Most of the debris which entered the troposphere at the time of testing will, on the basis of experience and theory, be removed within a month. Hence, from December 1961 through the following spring, the recent source of most debris in surface air must be the polar stratosphere, and therefore air must pass downward through the tropopause along sloping (of the order of 1 to 100) southward trajectories which are sharply terminated latitudinally at 20° to 30°N. Staley (*3*, *8*) has elsewhere shown examples and given a more complete account of trajectories of this type.

A spring maximum occurs again in 1962 in the northern hemisphere at about 28°N. There is some slight evidence again of a delay of the maximum with increasing latitude. The autumn minimum seems to be appearing again despite resumption of Soviet testing in August and September 1962.

The remaining feature of interest in Fig. 1 is the southward drift into the southern hemisphere of debris from U.S. nuclear testing, which was resumed at Christmas Island (2°N, 157°W) on 25 April 1962. There is no clear evidence from Fig. 1 that any debris from this source appeared in surface air at any of the northern hemisphere stations. However, radiochemical analysis will no doubt show that at least *some* debris entered the northern hemisphere. A complete accounting of the distribution will require consideration of synoptic meteorological observations made at and shortly after the time of detonation. The appearance of larger concentrations at Chacaltaya than at Lima could result from altitude differences or from passage south of Lima of the main concentration before it passed through the 80th meridian.

Junge (*5*) and others have calculated "exchange rates" between the northern and southern hemisphere by assuming that the rate of transport from one hemisphere to the other is given by a constant of proportionality times the difference of tracer content between the hemispheres. The contrast in Fig. 1 between United States and Russian debris transports shows that interhemispheric transport depends crucially on where within the hemisphere debris is concentrated.

Some debris was injected into the troposphere from low yield devices detonated in July 1962 in Nevada. However, either because the atmospheric yield was small or because the plumes, starting a relatively short distance upwind, passed between the stations of the 80th meridian, this debris makes no obvious appearance.

Many of the uncertainties of interpretation may originate from variations of concentration with longitude, particularly shortly after detonations a short distance westward from the 80th meridian. Additional insight may be gained by analysis of activities of individual radioisotopes and activity ratios in a latitude-time section. However, these are at present available only as averages at bimonthly intervals (*9*). Sampling along an additional meridian would be very desirable (*10*).

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Maskelynite: Formation by Explosive Shock

Abstract. *When high pressure (250 to 300 kilobars) was applied suddenly (shock-loading) to gabbro, the plagioclase was transformed to a noncrystalline phase (maskelynite) by a solid-state reaction at a low temperature, while the proxene remained crystalline. The shock-loaded gabbro resembles meteorites of the shergottite class; this suggests that the latter formed as a result of shock. The shock-loading of gabbro at 600 to 800 kilobars raised the temperature above the melting range of the plagioclase.*

Maskelynite, an amorphous form of plagioclase, was discovered by Tschermak (*1*) as a major constituent of the Shergotty meteorite which fell in India in 1865. This meteorite is a basaltic achondrite, similar in composition and texture to many terrestrial gabbros. The major phases are maskelynite, of labradorite composition, and pyroxenes, which are mostly pigeonitic. Although maskelynite appears to be a clear isotropic glass, the grains have the rectangular outlines commonly shown by plagioclase crystals in gabbros; they also have straight cracks corresponding to feldspar cleavages. In contrast, the pyroxenes exhibit normal petrographic properties. Shergotty and one similar meteorite, which fell at Padvarninkai, Lithuania, in 1929, are the only representatives of the shergottite class.

The unusual characteristics of shergottite could be explained if maskelynite had formed from plagioclase by a solid-solid transformation rather than by ordinary fusion. Such transformations have been reported for quartz and other silicates as a result of a very intense neutron flux (*2*) and as a result of explosively generated shocks (shock-loading) (*3*). We now report the experimental production of a rock similar to shergottite by shock-loading of an ordinary gabbro.

Gabbro from the Stillwater complex in Montana was chosen since it is similar in texture and mineralogy to shergottite. The specimen was composed of plagioclase of about An_{80} composition and a lamellar orthopyroxene of the Bushveld type (*4*), in which the narrow exsolved lamellae are presumably diopsidic pyroxene.

Two wafers, 17 mm in diameter by 2 mm thick, were placed in a steel container, separated by an attenuator. The container, protected against spalling by momentum traps, was impacted by a steel flying plate (1.25 mm thick) that had been explosively accelerated to a velocity of approximately 4.5 km/sec (*5*). The container was unbroken, although somewhat deformed by the shock. Fairly large coherent fragments of both wafers were recovered and cut into thin sections. Peak pressures and temperatures during shock in these specimens were estimated by a graphical method with the aid of the Hughes-McQueen equation of state for gabbro and available handbook tabulations of thermodynamic data for gabbro at low pressures (*6*).

Peak pressure in the upper, more strongly shocked, specimen is estimated to have been in the range of 600 to 800 kb. For this specimen a temperature during shock of 1700° to 2100°C was calculated, which fell adiabatically to 1300° to 1700°C immediately after shock. For the lower specimen a peak pressure in the range of 250 to 350 kb was estimated. The maximum temperature during shock was calculated to have been 200° to 300°C, which fell adiabatically to 200° to 250°C immediately after the shock. On the basis of previous calorimetric calibrations of the experimental system, it can be estimated that post-shock heating of the lower specimen by conduction from the hotter portions of the container resulted in a final temperature of no more than 350°C.

In the lower specimen, which was shocked to 250 to 350 kb, the plagioclase was entirely transformed to maskelynite similar to that in the Shergotty meteorite. Examination in thin section shows grain outlines and cleavage cracks that are pseudomorphous after those of the original plagioclase (Fig. 1). The cracks and lines of inclusions