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by

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ABSTRACT

The elemental composition of 111 plutonium-bearing particles was determined (using an electron microprobe) as part of a program to investigate the origin and behavior of the long-lived transuranic radionuclides released from fuel reprocessing facilities at the Savannah River Plant. These particles, collected from wet-cabinet and room-air exhausts from the plutonium finishing operation (JB-Line), were between 0.4 and 36 μm in diameter. Ninety-nine of the particles were found to be aggregates of various minerals and metals, six were quartz, and six were small (<2-μm-diameter) pieces of iron oxide. Collectively, these particles contained less minerals and more metals than natural dusts contain. The metallic constituents included elements normally not found in dusts, e.g., chromium, nickel, copper, and zinc. Concentrations of aluminum and iron exceeded those normally found in minerals. Elemental concentrations in individual particles covered a wide range: one 2-μm-diameter particle contained 97% NiO, a 9-μm-diameter particle contained 72% Cr_2O_3. Although the particles were selected because they produced plutonium fission tracks, the plutonium concentration was too low to be estimated by microprobe analysis in all but a 1-μm-diameter particle. This plutonium-bearing particle contained 73% PuO_2 by weight in combination with Fe_2O_3 and mica; its activity was estimated at 0.17 pCi of ^{239}Pu.

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COMPOSITIONS OF AIRBORNE PLUTONIUM-BEARING PARTICLES FROM A PLUTONIUM FINISHING OPERATION

INTRODUCTION

The continuing release of small (<1 mCi/yr) quantities of plutonium in particulate form from fuel reprocessing facilities at the Savannah River Plant (SRP) has resulted in the initiation of a program to determine the origin and subsequent environmental behavior of this long-lived radioactivity source. The objective of initial studies is to determine the chemical composition and physical form of these plutonium-bearing particulates in various parts of the chemical separations process exhaust system. In this study airborne particles bearing plutonium were isolated from one of two exhaust systems in the plutonium finishing operation (JB-Line) in Building 221-F and analyzed by electron microprobe to determine the form and chemical composition of plutonium carriers released to the environment.

METHODS

Air is exhausted from the JB-Line by two systems. The system selected for this study draws air from the wet cabinets, where plutonium is in solution, and work areas and exhausts it via the JB-Line stack. Air from the other system, which exhausts the mechanical line, air dryer system, process vacuum system, and furnace off-gas via the 291-F stack will be studied later.

Between February 19 and March 6, 1975, five samples of unfiltered wet-cabinet exhaust were taken. Between May 23 and June 20, air was sampled almost continuously from five locations in the system. These samples included two from unfiltered wet-cabinet exhausts, one from unfiltered room air, one from the combined filtered wet-cabinet exhaust, and one from the exhaust from the JB-Line stack.

Samples of exhaust air were filtered at 100 ml/sec through 47-mm-diameter polycarbonate membrane filters having 0.1-μm-diameter pores. The filters were operated for periods that varied in length from one day for unfiltered air to 28 days for the stack exhaust.

After air was filtered by membrane filters, each filter was placed in a small glass vial and dissolved in 3/4 ml of chloroform. The chloroform solution was evaporated on a glass plate to form a clear polycarbonate film containing the particles. Particles bearing plutonium were identified by irradiating the film with 4×10^{13} thermal neutrons/cm^2. Fission fragments from plutonium sensitized the polycarbonate resin along paths leading from these particles. The sensitized film was etched for ten minutes in 6N NaOH at 50°C to reveal fission-fragment tracks.

Polycarbonate squares containing particles with fission fragment tracks were excised from the film and placed on a polished beryllium sample-mounting block that was one inch in diameter and scribed with a grid of numbered one-mm squares. The tracks in each polycarbonate square were photographed. The beryllium block was then placed in a low-temperature oxidizer, where a major portion of the polycarbonate was oxidized in an oxygen plasma containing 10% carbon tetrafluoride. (Polycarbonates are self-extinguishing and thus extremely difficult to oxidize.) Particles containing plutonium were identified after oxidation by photographing the same location on the beryllium block at the same magnification and comparing photographs made before and after oxidation.

The particles selected for analysis came from twelve filters that were used to sample unfiltered exhaust. No fission-fragment tracks could be found among the particles collected from the JB-Line stack. Most of the plutonium-bearing particles collected from filtered air produced only one or two tracks. A summary of the sources of selected particles is given in Table 1.

A total of 111 particles were mounted on four beryllium blocks; the number of particles on each block was between 16 and 37. The particles were analyzed on an electron microprobe.* Analytical data included measurements of x-ray intensities and estimates of particle size and shape. These data, along with estimated average densities, were used in the FRAME program[1] as modified for particles work by Armstrong[2] on a *UNIVAC*** 1110 computer. This calculation gave the particle composition in both element and oxide weight percents and atomic proportions based on 24 for oxygen atoms.† (Oxygen was not measured as such; elements were simply assumed to be present in the oxide form.)

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* The analyses were made at Arizona State University in Tempe, with a Cameca MS46 electron microprobe equipped with four crystal, wave-length-dispersive spectrometers (take-off angle, 18°) and *EDAX* 701/*MICROEDIT* (trademark of EDAX International, Inc.) energy-dispersive analyzer.

** Trademark of Sperry Rand Corporation.

† Analytical results are reported in atomic proportions based on 24 for oxygen because this method will more frequently provide whole numbers for the elemental composition of pure minerals. This is a standard geochemical procedure.

TABLE 1

Source of the Particles Selected for Analysis

Sample Collected	*Membrane Filter Number*	*Days on Which Filter Was Used*	*Number of Particles Analyzed*
Unfiltered wet cabinet exhaust	1	1	3
	2	2	5
	3	9	3
	4	14	5
	5	15	8
	6	98	6
	7	99-103	8
			38
Unfiltered wet cabinet exhaust	1	98	4
	2	99-103	9
	3	107-113	54
			67
Unfiltered room air exhaust	1	94-98	3
	2	99-103	3
			6

RESULTS

Overall Composition

A total of 17 elements were found in the particles. The most common elements were silicon and iron. All but six of the 111 particles contained SiO_2. These six were small Fe_2O_3 particles, about 2 µm in diameter. Five particles were collected from unfiltered wet-cabinet exhaust on June 5, 1975. Iron was as prevalent as SiO_2, being present in 106 of the 111 particles. The only particles not containing iron were five quartz particles. (In all, there were six quartz particles, all collected from unfiltered wet-cabinet exhaust on June 5. One, however, contained less than 0.5% Fe_2O_3.) Eighty-seven of the particles contained alumina (Al_2O_3).

Mineral Content

The abundance of silica and alumina suggests the presence of minerals. Most commonly found minerals in the SRP region include silica, kaolin clay, mica, and feldspar. The chemical composition of these minerals can be expressed in terms of silica, alumina, potassium monoxide, and water (see Table 2). Silica or quartz is the only one of these that contains no alumina.

In both kaolin clay and mica, the molecular ratio of alumina to silica is 1:2. Clay differs from mica in that clay contains no potassium and has more water. The molecular ratio of alumina to silica in feldspar is 1:6.

TABLE 2

Chemical Composition of Silica, Alumina, Kaolin Clay, Mica, and Feldspar

Class	*Mineral*	*Formula*	*Composition*
Silica	Quartz	SiO_2	SiO_2
Kaolin clay	Kaolinite	$Al_4Si_4O_{10}(OH)_8$	$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$
Mica	Muscovite	$KAl_2Si_3AlO_{10}(OH)_2$	$K_2O \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$
Feldspar	Microcline	$KAlSi_3O_8$	$K_2O \cdot Al_2O_3 \cdot 6SiO_2$

To determine what minerals might be represented in these particle samples, the percents of alumina versus silica were plotted in Figure 1. This plot is in the form of an isosceles right triangle, the hypotenuse of which is the locus of percents of alumina and silica in particles containing only these two constituents. The plot also contains two oblique lines. The upper line represents the ratio of alumina to silica in mica and clay and is the maximum concentration of alumina which would be expected as aluminosilicates. All points above this line represent particles containing alumina uncombined with silica. The lower line represents the combination found in feldspar. The mica and feldspar lines do not extend to the hypotenuse, because these minerals also contain potassium monoxide and thus the sum of the percents of alumina and silica must be less than 100. Points along the abscissa represent particles that contain no alumina. Points falling between the upper oblique line and the abscissa represent aggregates of clay, mica, feldspar, and quartz. One point fell beyond the feldspar line. In this case, the particle contained very little potassium (0.5% K_2O); it was thus assumed to be an aggregate containing 47% quartz, 42% clay, and only 3% feldspar.

The mineral composition of the particles was assessed by proportioning the percents of silica, alumina, and potassium monoxide into clay, mica, feldspar, and quartz fractions. Assumptions used for this proportioning are given in Appendix A. The relative distributions of these minerals are given in Table 3. Except for the six quartz particles, no particle contained more than 65% of any one mineral, and few contained more than 30%.

A sum of the mineral content of the particles is given in Table 4 along with the distribution of the other elements found in the particles. The prevalence of polymineralic aggregates is indicated by the higher median percent for the total mineral content. Seventy-three percent of the particles containing minerals had more than one: 37 had two and 40 had three. Of those with only one mineral, 18 contained silica and 10 contained mica. Half the particles were over 35% mineral and nine were over 80%.

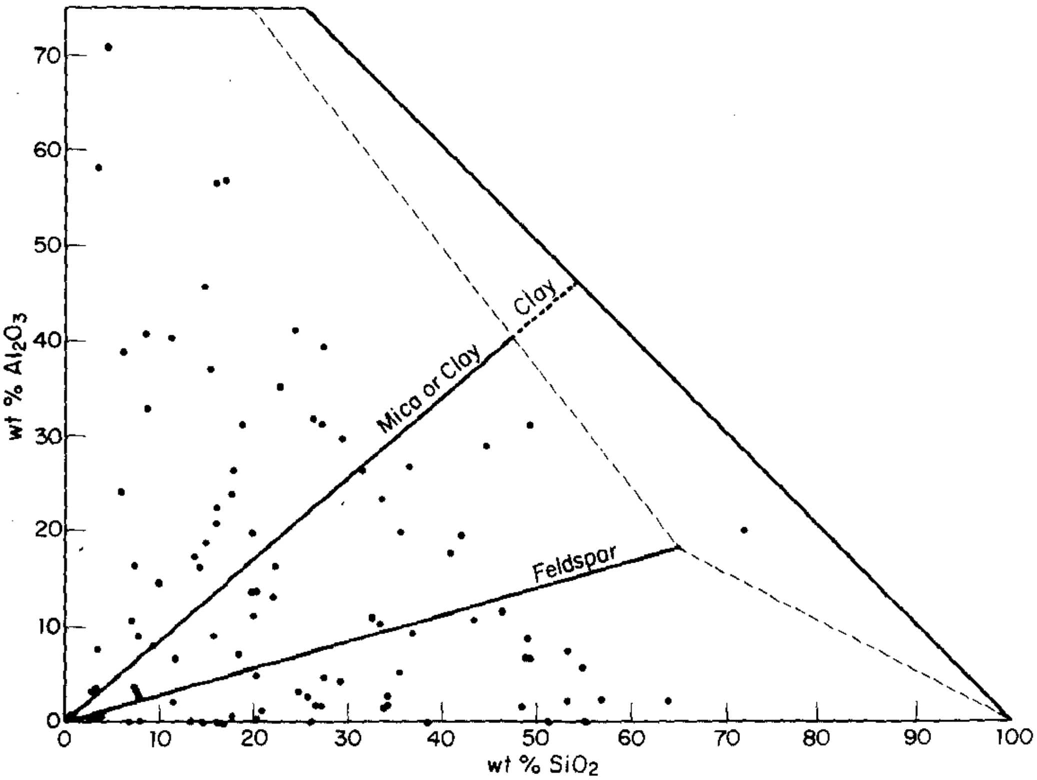

FIGURE 1. Relationships Between Weight Percents of Al_2O_3 and SiO_2 in Analyzed Particles

TABLE 3

The Percent Distribution of Clay, Quartz, Feldspar, and Mica in the Analyzed Particles

% of Mineral in Particles	*Number of Particles*			
	Clay	*Quartz*	*Feldspar*	*Mica*
0.05 - 4.99	20	14	20	5
5.00 - 9.99	11	7	10	7
10.00 - 14.99	8	3	7	5
15.00 - 19.99	8	11	3	10
20.00 - 24.99	3	5	4	5
25.00 - 29.99	3	5	4	4
30.00 - 34.99	3	-	-	1
35.00 - 39.99	3	2	1	2
40.00 - 44.99	3	4	-	-
45.00 - 49.99	2	3	-	-
50.00 - 54.99	-	1	1	-
55.00 - 59.99	1	1	-	2
60.00 - 64.99	-	-	1	-
65.00 - 69.99				
70.00 - 74.99				
75.00 - 79.99				
80.00 - 84.99				
85.00 - 89.99				
90.00 - 94.99				
95.00 - 100.00		6		
Total Number	65	62	51	41
Median %	11.0	17.1	8.2	16.3

TABLE 4

The Percent Distribution of the Minerals and Constituent Oxides in the Analyzed Particles

% of Material in Particles	*Number of Particles*															
	Minerals	Fe_2O_3	TiO_2	ZnO	CaO	NiO	Cr_2O_3	MgO	CuO	Al_2O_3	K_2O	SO_3	MnO	Cl	WO_3	PuO_2
0.50- 4.99	4	7	53	33	42	43	44	23	26	9	27	10	3	3	1	
5.00- 9.99	7	17	14	20	15	7	7	11	7	8	1		3			
10.00- 14.99	9	17	1	10	7	2	5	5	4	2	3	1	2			
15.00- 19.99	10	6	2	2	2	3	1	5	1	4		1	1			
20.00- 24.99	4	12	1	6	1	3	1	2		1						
25.00- 29.99	9	12	1		1					1						
30.00- 34.99	8	5				1				4						
35.00- 39.99	14	6	2	1	1	1		1								
40.00- 44.99	2	5	1		1	1			1	2						
45.00- 49.99	6	2		1												
50.00- 54.99	4	3						1		1						
55.00- 59.99	6	2				2										
60.00- 64.99	9															
65.00- 69.99	4	3						1		1						
70.00- 74.99							1									1
75.00- 79.99		1														
80.00- 84.99	1	1														
85.00- 89.99	1	1														
90.00- 94.99	1															
95.00-100.00	6	6				1										
Total Number	105	106	76	73	70	64	59	49	39	33	31	12	9	3	1	1
Median %	35.1	22.7	2.1	5.7	3.3	3.0	2.2	5.8	1.9	9.2	1.8	1.2	8.5	3.4	1.2	73.4

Plutonium Content

All particles selected for analysis produced fission-fragment tracks and thus contained plutonium. However, plutonium was detected by electron microprobe analysis in only one. (The detection sensitivity of the microprobe analysis for plutonium is 10 fCi). This was a small (1-μm-diameter) particle collected from the unfiltered wet-cabinet exhaust on May 28 which contained 73 wt % PuO_2. The other major constituents were Fe_2O_3(14%); CaO, CuO, and ZnO (about 1% each); and mica (6%). The volume of the PuO_2 was only 51% of the particle volume because the density of PuO_2 (11.46 g/cm^3) is much higher than that of the oxides of the other constituents (2.3 - 6.7 g/cm^3). A 1-μm-diameter sphere has a volume of only 5.2×10^{-13} cm^3. Thus this particle contained about 2.7×10^{-13} cm^3 of PuO_2 or about 2.7 pg of ^{239}Pu with an activity of 0.17 pCi.

Metallic Particles

Another small (2-μm-diameter) particle contained 97% NiO with about 1% each of CuO and ZnO. Two other particles contained about 55% NiO. These two also contained 12% mineral and about 12% Fe_2O_3.

Although they were collected from the same location, one was collected six days later and was twice the size of the other. A fifth particle, collected from the unfiltered wet-cabinet exhaust on June 5, contained 42% TiO_2 and 1% WO_3. The other major constituents were chromium, manganese, iron, and silicon.

Size Distribution

The size distribution of the particles is given in Table 5. The diameters ranged from 0.4 to 36.0 μm. From the size of these particles, 69% would be classed as silt and the remainder as clay. 58% might also be classified as dust.

TABLE 5

The Size Distribution of the Analyzed Particles

Particle Diameter, μm	*Number of Particles*
0.4 - 1.9	34
2.0 - 3.9	30
4.0 - 5.9	11
6.0 - 7.9	6
8.0 - 9.9	8
10.0 - 11.9	5
12.0 - 13.9	2
14.0 - 15.9	2
16.0 - 17.9	4
18.0 - 19.9	4
20.0 - 21.9	1
22.0 - 23.9	0
24.0 - 25.9	1
26.0 - 27.9	1
28.0 - 29.9	0
30.0 - 31.9	0
32.0 - 33.9	0
34.0 - 35.9	1
36.0 - 37.9	1
Total	111

DISCUSSION

For comparison, a brief description of the size, composition, and source of other airborne particles is provided in Appendix B.

The particles collected from the JB-Line have a lower mineral content than that of natural dust. Only eight particles had a silica concentration in the range of normal loamy soil; silica concentrations of eleven were in the range of loessial or unweathered soil. The average silica concentration, which is a better parameter for comparing bulk rather than individual particle analyses, was only 27%. This is half that of loessial soil, which contains between 50% and 60% silica. The average alumina concentration was 13%, which is the upper range for that in soil. However, 33 particles contained alumina in excess of that which would combine with mineral silica. The calcium or lime concentration in 70 particles exceeded that found in weathered loamy soil. However, in only six did the lime concentration exceed the higher values associated with unweathered loessial soil. Magnesium was found in 49 particles. Like calcium, these concentrations fell within the range in loessial soil but were higher than concentrations in weathered loamy soil. 49 of the 76 particles containing titanium had much higher concentrations of this element than that found in a composite sample of either loamy or loessial soil.

The particles collected from JB-Line also contained elements which are not found in appreciable quantities in either soil or natural dusts. Zinc was found in 73 of the particles. One contained as much as 35% and another 47% ZnO. 64 particles contained nickel. One small (2-μm-diameter) particle was almost totally nickel (97% NiO). Two contained between 55% and 56% NiO. Chromium was found in 59 particles. One large (9-μm-diameter) particle contained 72% Cr_2O_3. Thirty-nine particles contained copper, one with as much as 41% CuO.

These analyses support the conclusion that most of the plutonium-bearing particles are dust composed of polymineralic aggregates containing anthropogenic material. Some coagulation must have occurred in the wet cabinets where submicroscopic plutonium particles were added to the growing mineral aggregate nuclei. The source of the mineral nuclei on which coagulation occurred was probably ambient dust. However, nothing is known about the composition of the ambient dust. The chromium and nickel in some particles may have come from the 304L stainless steel of cabinets and exhaust ducts or the *Hastelloy**-*C* equipment in the cabinets. However, few of the particles contained the proper ratio of chromium-to-nickel found in either stainless steel or *Hastelloy-C*. Also, if

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* Trademark of Cabot Corporation.

Hastelloy-C contributed the nickel in the particles, some molybdenum should also have been detected in them. Sources of copper and zinc are unknown.

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APPENDIX A. PROCEDURE FOR CALCULATING MINERAL CONTENT OF PARTICLES

The following procedure was developed to express the percent silica, alumina, and potassium monoxide in terms of clay, mica, feldspar, and quartz. The objective of this procedure was to combine the existing elements in such a way as to give the smallest number of minerals containing as much of these elements as possible.

The ratio of the percent alumina to the percent silica, A/S, in each particle was calculated. If A/S exceeded 0.8485 (the ratio found in both clay and mica), the particle was assumed to contain alumina and either mica or clay or a combination of both. The percent alumina was calculated by subtracting 0.8485 from the observed A/S and multiplying by the percent silica. The ratio of the percent K_2O to the percent silica, K/S, was next calculated for the particles with A/S greater than 0.8485. If K/S exceeded 0.2613 (the ratio found in mica and feldspar), the particle was assumed to also contain K_2O. The percent K_2O was calculated by subtracting 0.2613 from the observed K/S and multiplying by the percent silica. The clay-mica fraction was then considered to be all mica equal in percent to the sum of the percents of the silica and unaccounted-for alumina and K_2O.

If A/S was less than 0.8485 but greater than 0.2828 (the ratio found in feldspar), the particle might contain any combination of the four mineral fractions. If K/S exceeded 0.2613, the minerals were limited to the mica and feldspar fractions. The fraction of these two which was mica, m, was obtained from the relationship

$$0.8485m + 0.2828(1-m) = A/S$$

or

$$m = \frac{A/S - 0.2828}{0.5657}$$

If K/S was less than 0.2613, some or all of the clay-mica fraction was considered to be clay. If all the clay-mica fraction was considered clay and there was insufficient potassium for the feldspar fraction, a portion of the feldspar fraction was considered to be clay and quartz where

1 mole feldspar = 1 mole K_2O + 1 mole clay + 4 moles quartz.

If A/S was less than 0.2828, the ratio of the percent K_2O to the percent alumina, K/A, was used to proportion the constituents. If K/A was greater than 0.9239 (the ratio found in feldspar), the particle was considered to contain K_2O, feldspar, and quartz. The percent feldspar was determined by the amount of alumina, and the excess silica was considered quartz. If K/A was less than 0.9239, the percent feldpsar was determined from the percent K_2O. Any excess alumina was calculated as clay, and the silica not accounted for in the clay and feldspar fractions was considered as quartz.

APPENDIX B. CLASSIFICATION OF SMALL PARTICLES

Presently accepted classifications as to size, composition, and source were used to describe the particles observed in this study.

Dusts, Mists, and Smokes

Dusts are air-dispersions of solid microparticles from either natural or anthropogenic sources. Natural dusts originate from minerals as a result of either weathering, volcanic eruptions, or disruption by crushing, grinding, drilling, or blasting. Anthropogenic dusts, on the other hand, are the result of industrial operations, transportation, insecticide dispersions, and combustion. In the popular sense, dust usually refers to solid particles which have settled on a surface and which can readily be redispersed into the atmosphere. Mists are liquid droplets usually formed by condensation of vapors but may also be produced by the atomization of liquids. (When the concentration of the suspensoid is sufficient to markedly reduce the visual range, a mist may be called a fog.) Smokes are either solid or liquid particles which are smaller than those of both dusts and mists.

Soil Particles

Table B-1 lists substances found in soil and air and their defined diameters. Dust particles are in size between a coarse clay and a fine silt. They are produced naturally from bedrock by the processes of weathering and coagulation. Weathering results in the mechanical disintegration and chemical decomposition of bedrock. The process is initiated by a physical weakening due usually to temperature changes. This is accomplished and supplemented by chemical transformations. Minerals such as feldspars, mica, and the like undergo hydrolysis and hydration, while part of the combined iron is oxidized and hydrated. The three transformations are outlined below.

TABLE B-1

Particle Size as Defined by Various Authors

Particle Designation	*Diameter, µm*	*Reference No.*
Monatomic or monomolecular ions	0.0001-0.0003	4
Intermediate ions	0.004 - 0.050	5
Langevin ions	0.050 - 0.114	6
Aitken nuclei	0.008 - 0.400	5
Tobacco smoke	0.01 - 0.15	7
Oil smoke	0.03 - 1.0	7
Dust	0.2 - 4.0	8
Mist	0.2 - 10.0	9
Erythrocyte (for reference)	7.85	
Clay	<2[a]	10
Silt	2 - 50[a]	10
Very fine sand	50 - 100[a]	10
Fine sand	100 - 250[a]	10
Medium sand	250 - 500[a]	10
Coarse Sand	500 - 1000[a]	10
Rain drop	500 - 5000	7

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[a] U.S. Department of Agriculture Classification.

Hydrolysis

$K_2O \cdot Al_2O_3 \cdot 6SiO_2 + 2HOH \rightarrow Al_2O_3 \cdot 6SiO_2 \cdot H_2O + 2KOH$

Microcline (Feldspar)

$$CO_2 + HOH \rightleftharpoons H_2CO_3$$

$$2KOH + H_2CO_3 \rightarrow K_2CO_3 + 2H_2O$$

Hydration

$Al_2O_3 \cdot 6SiO_2 \cdot H_2O + HOH \rightarrow Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O + 4SiO_2$

Kaolinite (Clay) Silica

$2Fe_2O_3 + 3HOH \rightarrow 2Fe_2O_3 \cdot 3H_2O$

Hematite Limonite

Oxidation

$4FeO + 3HOH + O_2 \rightarrow 2Fe_2O_3 \cdot 3H_2O$

Ferrous Oxide Limonite

The silica may crystallize to quartz or, more commonly, pass into a colloidal condition. Minerals soften, lose their luster, and increase in volume. Active cations as calcium, magnesium, sodium, and potassium become carbonated; and soluble mineral products are removed. As the process continues, all but the most resistant of the original minerals disappear, and their places are occupied by hydrated silicates that recrystallize into highly colloidal clay. The platelike nature of the clay particles and the lubricating yet binding influence of the absorbed water causes colloidal clay to form gels. This gives soils plasticity, that is, pliability and the capacity of being molded. It also inhibits colloidal clay from being dispersed in air.

Size of Particles from Weathered Soil

Most airborne dust particles are aggregates of smaller individual particles that tend to agglomerate in varying numbers. The reason for the adhesion of these fine particles to one another and to smooth solid surfaces is not known. Adhesion is attributed in part to the action of van der Waal's forces, the weak forces of attraction acting between all molecules. Although intermolecular attraction is weak and decreases with the seventh power of intermolecular distance, the attraction between two small particles each containing millions of molecules will be appreciable due to the combined effects of van der Waal's forces. If the minimum distance between two particles is constant, van der Waal's forces vary directly with their diameter, while forces tending to separate them, as aerodynamic drag and vibration, vary as the diameter squared and cubed, respectively. Thus molecular attraction becomes increasingly important as the particles become smaller with the smaller particles being harder to separate than larger ones.

Under atmospheric conditions, an additional attractive force between particles may arise from surface tension effects if condensed water films are present on them. However, particle aggregates remain intact when stored in desiccators.

Dust particles dispersed in air are known to carry electrical charges which could contribute to the mutual adhesion of particles forming aggregates. The force between two 0.5-μm particles carrying only one electron unit of charge each would consist mainly of the electrostatic and not of the molecular interaction. However, Armstrong and Buseck[3] found that deliberate surface charging of the host particles generally does not result in the repulsion of the adhering particles.

Once collodial clay particles become airborne, a process of continuous and spontaneous coagulation commences. As particles of collodial clay coalesce with particles of different material, they lose their platelike nature which is responsible for gel formation, the aerosol becomes coarser approaching silt in size, the rate of coagulation decreases as the particles grow, and finally the particles reach sufficient size to settle out on surface. Once the particles of collodial clay lose their platelike configuration, they become dust. Although Armstrong and Buseck[3] found a very large fraction of the airborne particles collected from the interior southwest are composed of combined mineral material, such as clays, micas, amphiboles, feldspars, calcite, and quartz, many are discrete monomineralic particles.

Size of Particles from Unweathered Soil

Whereas the clay colloids of originally clayey deposits aggregate to stable particles of silt size, in regions of moderate rainfall physical rock disintegrations practically stop at the silt fraction which may become airborne. In many parts of the United States, particularly in the Mississippi, Missouri, and Ohio valleys, there are large unconsolidated deposits of silty texture known as "loess." These deposits originated from dusts which were carried by the prevailing winds from the desert to the semihumid zones where the dust was precipitated by rain and held to the ground by the grass cover. Particles produced by crushing or grinding of minerals which have not gone through the weathering process to produce clay and silica will resemble loessial soil in composition.

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