

EXCHANGE OF LYOTROPIC SERIES CATIONS BY MICACEOUS
VERMICULITE AND ITS WEATHERING PRODUCTS DETERMINED
BY ELECTRON MICROSCOPY AND RADIOCHEMICAL ANALYSIS

Progress Report

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TECHNICAL PROGRESS REPORT

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Documentation

This progress report is submitted pursuant to Article B-XXI of the Contract, No. AT(11-1)-1515 which has been in operation since June 1, 1965. Under this contract to April 29, 1974, 31 scientific papers have been published or accepted for publication, seven additional papers have been submitted for publication, and eight others are in various stages of development for publication (all listed near the

end of this report). During the 3-year period August 1, 1971 to July 31, 1974, 12 scientific papers have been published, four additional papers have been accepted for publication, 6 have been submitted, and eight others are in various stages of development for publication (all included in the listing near the end of this report). The COO-1515 reporting status is summarized in the last three pages of this report.

Abstract

The work is summarized under three topics: (i) fission particle tracks of ^{238}U present in the octahedral sheet of micaceous vermiculite, after HF decoration, were photographed by scanning electron microscopy. Before HF treatment, diffusion of K^+ , Fe , and $\text{Si}(\text{OH})_4$ was enhanced by the presence of the tracks, and selective adsorption of fixing cations such as $^{137}\text{Cs}^+$ was increased. High resolution electron microscopy (HREM) revealed that the mixed-layer stacking sequence of most clays contain some micaceous vermiculite. Lateral variation along the (001) crystal planes was shown by blister morphology and also by HREM, thus demonstrating conclusively the existence of interlayer wedges active in selectivity of such cations as Cs^+ . (ii) Divalent cations of the $^{90}\text{Sr}^{2+}$ type and transition and heavy metal type are specifically sorbed by gel forms of hydrous oxides of Fe^{3+} and Al^{3+} which are almost universally present as coatings on soil particles. (iii) Tropospheric dusts, shown to circulate world-wide and accrete in soils, deep-sea sediments, and island mountaintops from rainfall, show significant reactions with fission products such as $^{137}\text{Cs}^+$ and $^{90}\text{Sr}^{2+}$, variable according to dust composition. They influence the fate of radioisotopic fission products in air and soil. The following script presents a summary of the findings, with references to the specific publications in which they are reported.

I. Cation exchange by micaceous vermiculite
and visual model by electron microscopy

a. Cation exchange selectivity influenced by uranium fission particle tracks. Perforations such as holes and cracks in micaceous vermiculites caused by fission of ^{238}U in the crystal layers and weathering were found (Jackson, Lee, Brown, Sachs, and Syers, 1973)* by scanning electron microscopy (SEM). Hydrous metal oxide crusts intercalated on occasional (001) cleavages and layer partings of micaceous vermiculite were observed by SEM through pores, holes, or fractures along (hk0) planes. The coatings of (Fe,Al) oxides were shown to occur as a spatter-pattern over intermittent cleavages while other cleavages were clean. The oxide distribution may build up over ^{238}U fission particle tracks, the latter being found in both primary micas and in vermiculite. Considerable number of ^{238}U fission particle tracks (200 to 500 cm^{-2}) were observed in micas and vermiculites after HF etching (Lee, Jackson, and Sachs, 1974). Diffusion of interlayer K^+ and structural Fe and $\text{Si}(\text{OH})_4$ occurred through the tracks produced by thermal neutron activation of ^{235}U . An increase of selectivity of K^+ over Ca^{2+} and cation exchange capacity during the extensive salt treatments of

* (Authors, date) refers to publications or manuscripts accepted for publication given in the first list of references appended.

micaceous minerals after activation suggests that an important role may be played by uranium fission particle tracks during chemical weathering of micaceous minerals in nature. The results indicate that the presence of fission particle tracks was partially responsible for the higher cation exchange capacity of muscovite macroflakes, determined radiochemically, compared to the theoretical value (Mokma, Syers, and Jackson, 1970). Direct determination of charge density by fission track distribution appears to be possible (Lee and Jackson, in preparation).^{*} Also, in micaceous New Zealand soils (Mokma, Jackson, Syers, and Stevens, 1973), the micaceous vermiculite content largely determined the sorption and fixation of $^{137}\text{Cs}^+$. The strength of fixation suggests that the fixed $^{137}\text{Cs}^+$ may not be released short of the decomposition of the micaceous vermiculite by weathering.

b. Phyllosilicate layer sequence visually revealed by high resolution electron microscopy. Ultramicrotomy (UM, cutting very thin sections with a diamond knife) and high resolution electron microscopy (HREM) permitted direct photography of layers and (Fe,Al) hydroxy interlayers of phyllosilicates (Brown and Jackson, 1973). Micrographs made before and after an appreciable irradiation from the electron

^{*}(Authors, in preparation) refers to manuscripts in the process of being prepared, in the third list of references appended.

beam revealed images of the 7A structural plane spacings of chloritized materials, representing the interlayer hydroxyl to layer hydroxyl (002) electron density nodes. Loss of the images at 7A intervals and reenforcement of those at 14A intervals was caused by heating in the electron beam. A finding of small micaceous domains in kaolinites observed by high resolution electron microscopy after ultramicrotome cutting of sections perpendicular to the layers (Lee, Jackson, and Brown, 1974a, submitted)* are expected to affect the structure and physicochemical properties of kaolinite weathering product of mica. Establishment by these UM-HREM studies of the presence of micaceous vermiculite in clays of highly weathered kaolinitic soils helps to explain properties important to fixation by clays of cations such as $^{137}\text{Cs}^+$ in radioactive wastes. Kaolinite layers were shown by the same technique freely to interstratify with montmorillonite, vermiculite, and mica (Lee, Jackson, and Brown, 1974b, submitted). This provides, for the first time, a firm scientific visual model for the crystal disorder of 1:1 and 2:1 layer mixing. The study provides a clearer understanding of fission cation fixing sites in natural clays, relevant knowledge on mica weathering to vermiculite, on the nature of

* (Authors, date, submitted) refers to manuscripts submitted for publication, in the second list of references appended.

interstratification, on interlayering of aluminum hydroxide in authigenic micaceous minerals (Jackson, Lee, Brown, and Veith, in preparation) and cation exchange of $^{137}\text{Cs}^+$ (Fig. 1) and adsorption of $^{90}\text{Sr}^{2+}$ in soils.

c. Layer charge decrease in relation to cation fixation.

Layer charge density both on (001) cleavage faces and on the layers forming wedges, in addition to cation charge and hydration, control cation exchange selectivity (CES) and Cs^+ fixing properties of micaceous vermiculite (Dolcater, Jackson, and Syers, 1972). Swelling of the layers of micaceous vermiculite in blister-like areas of lower charge were found to occur according to the lyotropic cation series: $\text{Li}^+ > \text{Na}^+ > \text{Be}^{2+} > \text{Mg}^{2+} > \text{Ca}^{2+}$ (Sridhar, Jackson, and Syers, 1972). That the blister areas had a lower charge was shown by fracturing them off while Li^+ saturated and separately characterizing the shattered-off soil. The swelling was found to be repressed by fixing monovalent cations, but was not completely prevented, as traced by electron microscopy and electron probe analysis, because hydrated cations were trapped by fixing cations in the order: $\text{Cs}^+ > \text{Rb}^+ > \text{NH}_4^+ > \text{K}^+$ (Sridhar and Jackson, 1973). Layer charge of iron-bearing vermiculites, which affects $^{137}\text{Cs}^+$ fixation capacity, was unaffected by 7 to 90 mmole/100 g of octahedral Fe oxidation and/or reduction (Veith and Jackson, 1974). An OH^- group is deprotonated when $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$, so that the layer charge



Fig. 1. High resolution electron micrograph of Cs^+ saturated micaceous vermiculite from Marblehead, Wisconsin: The micrograph shows 10.3\AA spacings which represent structural images of the (001) cleavage surfaces of the micaceous phase. The presence of occasional darker fringes in a particle indicate that the adsorbed Cs^+ in interlayer exchange sites have enhanced the contrast of the image through the higher nuclear density of Cs^+ than K^+ (Magnification of micrograph is 996,000X). From Jackson *et al.* (1974).

remains the same (Roth, Jackson, and Syers, 1969). The layer charge density appears to be variable in a reversible manner in soils in the field (Henderson, Doner, Weaver, Syers, and Jackson, in preparation). A phlogopite with little iron was found to weather through vermiculite to saponite involving a substantial layer charge decrease from 210 to 140 during the process (Jackson and Sridhar, 1974, submitted). These findings indicate that iron oxidation, long thought to be the mechanism of the layer charge decrease, is not the mechanism, but merely occurs concurrently. Investigations under this project revealed that the layer charge decrease was equivalent to the tetrahedral Al^{3+} and Fe^{3+} removed by natural weathering of the phlogopitic vermiculite; with several other micas treated with citric acid, the layer charge decrease as measured by CEC + K was equivalent to the tetrahedral Al^{3+} removed by the treatment (Sridhar and Jackson, 1974, submitted).

II. Hydrous iron and aluminum oxides in micaceous vermiculites

a. Films and crusts revealed on cleavage surfaces.

Mainly ferruginous sesquioxide coatings on micaceous vermiculite surfaces appeared in the early stages of soil development (less than 250 years) and increased in thickness and amount in the older soils of a chronosequence of soils developed in greywacke and mica-schist materials of New Zealand (Mokma, Jackson, Syers, and Stevens, 1973). Redistribution of iron oxides was indicated by the increase in the quantity of discrete goethite particles in the older soils. The amount of $^{90}\text{Sr}^{2+}$ adsorbed varied within a relatively narrow range but that fixed against replacement by Ca^{2+} in 0.01N CaCl_2 varied over a much wider range. The tendency for a decrease in the amount of $^{90}\text{Sr}^{2+}$ adsorbed and fixed with increasing age in the older soils indicates that the free iron oxides which adsorb and fix Sr^{2+} increase in crystallinity and become less active. Removal of ferruginous sesquioxides tended to decrease the extent of sorption and fixation of $^{90}\text{Sr}^{2+}$ but increased the extent of sorption and fixation of $^{137}\text{Cs}^+$, owing to increased layer charge density. Hydrous iron oxide with up to 20% aluminum co-mixed has been found on the (001) cleavage surfaces of micaceous vermiculite (Roth et al., 1967) readily visualized as crust under scanning electron microscopy (Jackson, Lee, Brown, Sachs, and Syers, 1973), as

described above. These coatings have a positive charge and neutralize some of the layer negative charge (de Villiers and Jackson, 1967; Roth et al., 1968, 1969). Layer charge density is important to cation exchange selectivity (Dolcater et al., 1968, 1972). Mica weathering has been especially reviewed as an aid to the project (Mokma et al., 1974).

b. Specific adsorption of divalent cations of the $^{90}\text{Sr}^{2+}$ type and transition and heavy metal types. Hydrous oxides of Fe and Al show a remarkable ability to adsorb trace quantities of Ca^{2+} and Sr^{2+} from solutions containing a million times more (LM) Na^+ (Kinniburgh, Syers, and Jackson, 1971, 1974). Analysis of the pH dependence of this absorption suggested that adsorption occurred by release of approximately one proton for each divalent cation adsorbed, the proton being derived from the weakly acidic surface functional groups. This stoichiometry has been confirmed directly by a titration procedure (Kinniburgh, Jackson, and Syers, in preparation), and gives complete confirmation of the original analysis. In contrast to nonspecific adsorption, most of the cation adsorption occurred while the solids possessed a net positive charge. Furthermore, since approximately one H^+ was released for each Ca^{2+} or Sr^{2+} adsorbed, the net positive charge of the surface is further increased by adsorption. This general result applies to a wide variety of divalent cations (Kinniburgh, Jackson, and Syers, in

preparation) and a wide range of naturally occurring soil minerals. The specific adsorption of the transition and heavy metal cations occurs at an appreciably lower pH than that of Ca^{2+} and Sr^{2+} (Fig. 2), and this has important implications to the mobility and availability of these ions in soils. The adsorption-pH curves for eight divalent cations on synthetic Fe and Al gels (Fig. 2) was carried out with each divalent cation present at an initial concentration of $0.125 \times 10^{-3} \text{M}$, and the relative position of the curves gives an indication of the strength of the divalent cation-gel interaction. The transition and heavy metal cations are adsorbed at a considerably lower pH than the alkaline earth cations, indicating stronger interaction with the gels. In all cases, the divalent cations are adsorbed at a lower pH than the cations would be precipitated as the metal hydroxides, indicating that adsorption is preferred to precipitation. Interestingly, the cation selectivity sequence on the two gels is different, reflecting the differing ability of the cations to fit into the surface structure of the gels. Detailed studies of Zn^{2+} adsorption indicate that the M^{2+} - H^+ stoichiometry of adsorption is significantly different from that of Ca^{2+} , with 1.6-1.7 protons released for each Zn^{2+} sorbed as opposed to a value of about one for Ca^{2+} (Kinniburgh and Jackson, in preparation). This is probably also true for the other transition metal cations and

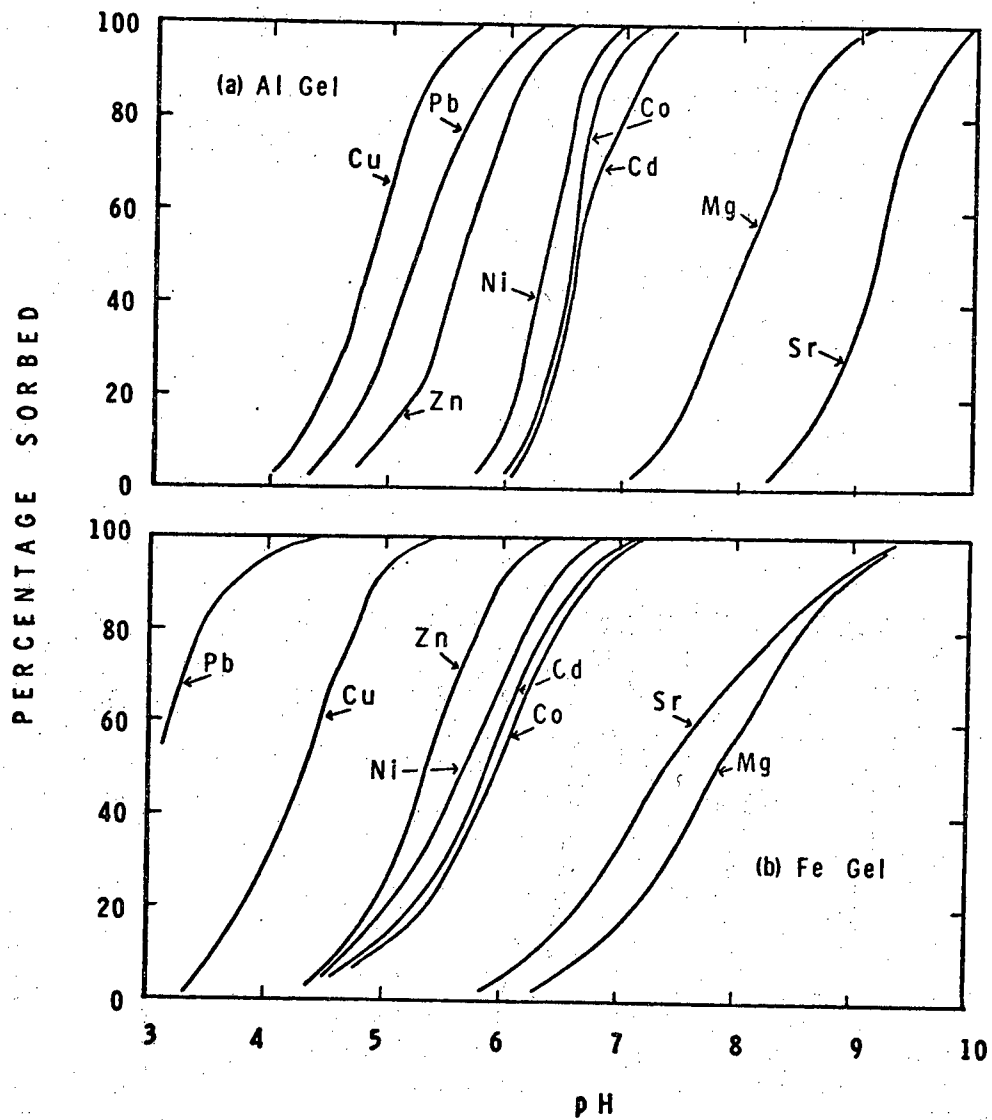


Fig. 2. Adsorption-pH curves for eight divalent cation on freshly prepared hydrous metal oxide gels. (a) Al gel (0.093 M Al); (b) Fe gel (0.093 M Fe). Each divalent cation was present at an initial concentration of 0.125×10^{-3} M and the gels were suspended in 1 M NaNO_3 . From Kinniburgh, Jackson, and Syers, in preparation.

indicates a significant difference between the two groups of cations. Detailed interpretation of these results, with further experimental and theoretical studies, is expected to aid in understanding in the retention by soils of fission products.

While adsorption may be important in determining the rate of movement of a substance through a soil profile, in the long term, the fate of many (inorganic) pollutants depends on whether they can be removed from the soil's labile pool - i.e. irreversibly 'fixed'. This fixation is frequently very slow, difficult to study experimentally, and consequently difficult to incorporate into general models. This fixation is frequently achieved by incorporation into a mineral structure, and the hydrous metal oxides are certainly able to fix certain cations in their structure. However, the ionic criteria favoring structural incorporation are somewhat different from those favoring sorption, and so as a gel ages, some of the sorbed ions are incorporated while others are excluded and desorbed.

The Al gel, in particular, has a tendency to crystallize, and during this process, some of the smaller cations, particularly the transition metal cations, are incorporated into the bulk crystal structure. The larger cations, such as Sr^{2+} , are excluded and therefore desorbed as crystallization proceeds.

The Al gel, and to a lesser extent the Fe gel adsorbs Ca^{2+} more selectively than Sr^{2+} , and so the fate of Sr^{2+} in the environment will be closely related to the fate of Ca^{2+} , a major soil cation. This suggests that most of the $^{90}\text{Sr}^{2+}$ will probably remain in the labile pool of soil cations, and available for plant uptake, until it is physically removed from the plant root zone, or until it is ultimately occluded along with Ca^{2+} in major Ca bearing minerals, such as the calcium carbonates. However, since $^{90}\text{Sr}^{2+}$ has a half-life of about 28 years, probably only a very small fraction of the terrestrial burden of $^{90}\text{Sr}^{2+}$ will be incorporated into crystal structures since decay to yttrium and other daughter products probably occur at a faster rate than crystal structural incorporation.

III. Relation of aerosolic minerals in dusts to fate of fission-produced radioisotopes in air and soil

a. Radiotracer studies. The aerosolic (tropospheric) dusts, found in this project by the use of the oxygen isotope composition of the mineral quartz to have accreted in soils and sediments in a wide range of locations throughout the world (Jackson, 1974), have been shown to contain micaceous vermiculite which is responsible for the sorption and strong fixation of $^{137}\text{Cs}^+$ (Syers, Mokma, Jackson, Dolcater, and Rex, 1972). The dusts, which varied in their $^{137}\text{Cs}^+$ content

depending on locality and time of deposition, but all adsorbed significant amounts of added $^{137}\text{Cs}^+$ and strongly fixed it against replacement by Ca^{2+} in 0.01N CaCl_2 solution used to simulate natural soil conditions. The specific activity of $^{137}\text{Cs}^+$ on eight aerosolic dusts collected from snow and ice, from mud-rains, and from the atmosphere at several localities in the world ranged from 0 to 264 pc/g. Zero values were obtained for dust samples collected from a mud-rain in England (deposited in 1968) and from an ice-core in Greenland (deposited pre-1940). A sample separated from melted ice collected on the Franz Josef glacier in New Zealand contained 264 pc/g of $^{137}\text{Cs}^+$; a relatively high proportion of the $^{137}\text{Cs}^+$ on the latter sample could not be replaced by five consecutive washings with 0.01N CaCl_2 , indicating a strong fixation by the micaceous vermiculite component of the dust. The fact that all of the dust samples exchanged significant amounts (30 to 50%) of added carrier-free $^{137}\text{Cs}^+$ into fixation positions suggests that the absence or presence of only small amounts of $^{137}\text{Cs}^+$ on dusts is related to the lack of nuclear testing at the time when the dust was transported. A pelagic sediment from the north central Pacific and a soil from the Hawaiian Islands, both of which contain weathered micaceous minerals of eolian origin, also exchange-fixed appreciable amounts of added $^{137}\text{Cs}^+$. This implies that aerosolic dusts have the ability

to adsorb any $^{137}\text{Cs}^+$ incident in rainwater just as dusts do following deposition in sediments or soils. The fixation of Cs^+ by micaceous vermiculite in dusts would greatly decrease the health hazard, since dust is easily washed from the skin and hair of animals.

b. Global relationships of dusts. An investigation was made of the pathways and sources of aerosolic dusts on a global scale (Jackson, Gillette, Danielsen, Blifford, Bryson, and Syers, 1973). The meteorological conditions required to dislodge dust in the hot, dry, Southwestern States (SWS) involves a strong pressure gradient involving upper-level jet (300 mb level) moving from Japan over the Gulf of Alaska. This air is deflected to the right (in its direction of travel) and descends as it travels along the British Columbian coast. Over California and Arizona, the decreasing speeds (now reduced to 60 to 80 kts from 100 to 150 kts it had at 300 mb) of the descending, south-moving air moves eastward in a large scale convergence with the heated, mixed volume of air in SWS with no buoyant forces to resist its downward motion. Momentum is rapidly transferred toward the soil surface. The gusts of strong wind involved in the vertical transport of momentum (air friction) is important in breaking up the soil. The dust is lifted by the compensating ascending plumes. Mean wind speeds of 30 to 50 kts are maintained by the cold-front pressure gradients and the dust

storm spreads. Similar dust-storm producing conditions occur in the principal global arid regions.

Beta-counts of the air establish that a portion of the stratosphere air (4 to over 200 dpm/SCF), as a fold of the tropopause, was transported downward into the cold front (20 to 87 dpm/SCF) and mixed with the dusty air (Fig. 3). Tropospheric air gave only 1 or 2 dpm/SCF. The importance of dust minerals in sequestering radiation emitting elements is thus apparent.

In the North Pacific area, oxygen isotopic values of quartz isolated from 25 soils developed over quartz-free basalt in several Hawaiian Islands (Jackson, Levelt, Syers, Rex, Clayton, Sherman, and Uehara, 1971) and from 22 North Pacific, deep-sea, pelagic sediments (Clayton, Rex, Syers, and Jackson, 1972) were remarkably similar ($\delta^{18}\text{O}$ averaging 17.6 and 17.8 o/oo, respectively), suggesting a common eolian origin over a very broad region. The oxygen isotope abundance (13.6 to 15.4 o/oo) in quartz from Australian soils developed in a chronosequence of quartz-free basalt and from associated soils in sedimentary rocks (Mokma, Syers, Jackson, Clayton, and Rex, 1972) and the particle size distribution of the quartz indicate that the quartz originated by eolian transport from stranded beach ridges and dunes occurring many km windward (Jackson, Gibbons, Syers, and Mokma, 1972). These soils were much less effective than soils and dusts

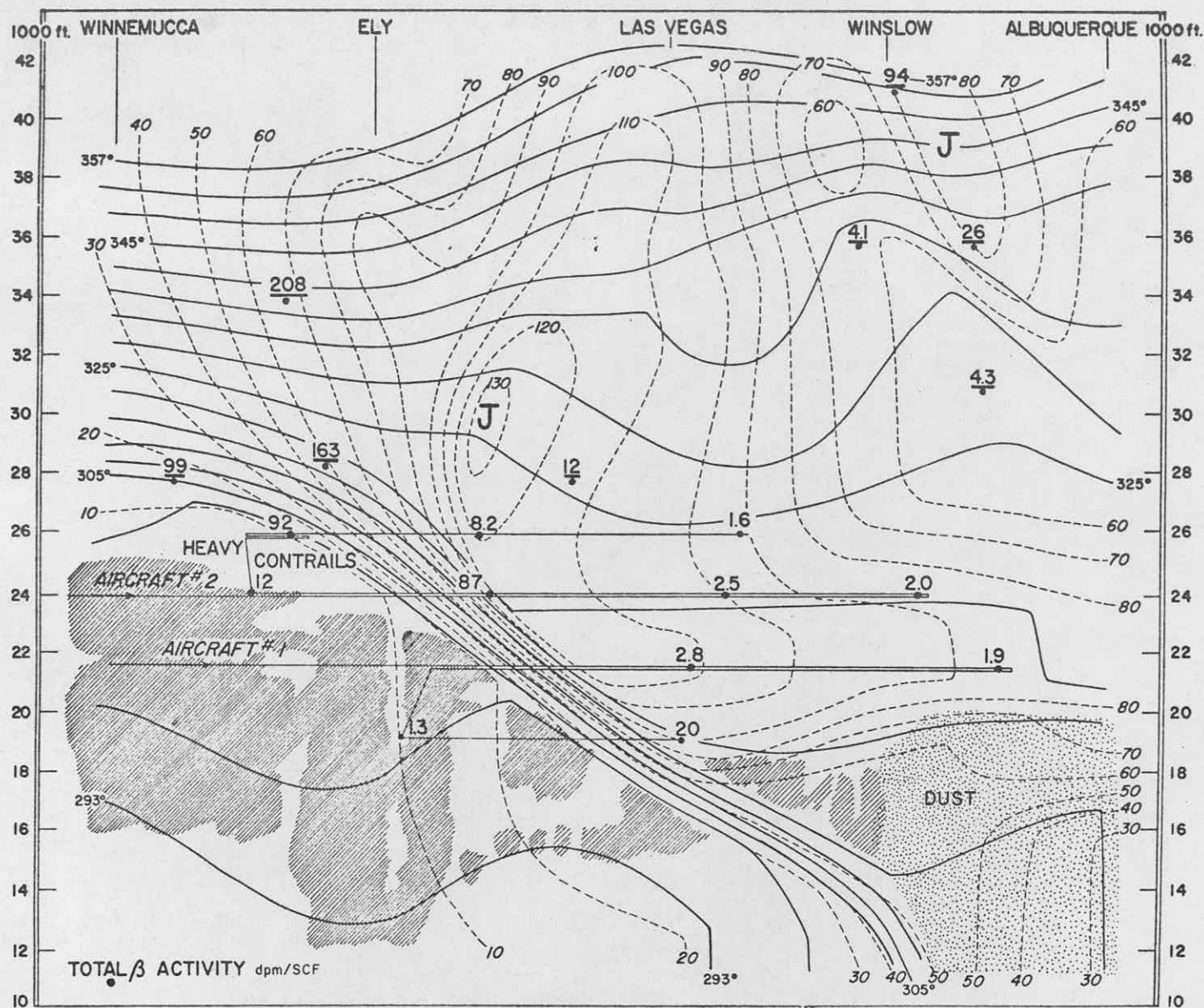


Fig. 3. Vertical cross section for midnight (Greenwich time) April 22, 1963. Solid lines are $\theta^{\circ}\text{K}$ at 4° intervals; dashed lines are isotachs (knots); J = jets; crosshatching = clouds; radioactivity, dpm/SCF = disintegrations per minute per standard cubic foot of air. From Jackson et al., 1973; Danielsen, 1964).

containing micaceous vermiculites in fixing $^{137}\text{Cs}^+$ and $^{90}\text{Sr}^{2+}$ against 0.01N CaCl_2 (Mokma, Jackson, Syers, and Gibbons, 1973).

c. Origin of aerosolic dusts. Variations in oxygen isotopic composition of quartz in dustfall at different latitudes (Jackson et al., 1973; Jackson, 1974) had led to investigation of principles governing the fluvial and eolian mixing of minerals during accumulation in sediments (Churchman, Clayton, Sridhar, and Jackson, 1974, submitted). Shales were found to be the principal reservoir ($\delta^{18}\text{O} = 17$ to 23 o/oo) of fine silt which cycles into soils and dusts. The fluvial mixing process from granitic (Wis.) and shale headlands is under study in the Mississippi River system (Clayton, Jackson, and Sayin, in preparation). In control experiments on isotopic exchange in quartz (Sridhar, Jackson, and Clayton, in preparation), overgrowths of silica on quartz particles were found to be a negligible factor in the intermediate oxygen isotopic ratios found in silty sediments. Study of the arid SWS (USA) area compared to Asia as a source of long range eolian dust is underway (Gillette, Clayton, Sridhar, and Jackson, in preparation).

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C00- 1515	Sent		Author, Journal, Content	Manuscript date
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1	x	na	Science Information Exchange form	15 July 65
2	x	na	Science Information Exchange form	1 Mar 66
3	x	x	Roth <u>et al.</u> , ISSS, Aberdeen (1967) Ver sesquioxide coatings	1 Oct 66
(4)	x	na	Jackson, Trip Report, Aberdeen	1 Oct 66
5	x	x	de Villiers and Jackson, SSSAP (1967) Al/(OH) ₂ pH/CEC	9 Jan 67
6	x	na	Technical Progress Report (1967)	1 Feb 67
(7)	x	na	Renewal Proposal	14 Feb 67
(8)	x	na	Single Column Budget	14 Feb 67
(9)	x	na	Statement of costs	14 Feb 67
(10)	x	na	Equipment report	14 Feb 68
11	x	na	Science Information Exchange form	14 Feb 67
12	x	na	Science Information Exchange form	24 Feb 68
13	x	x	Roth <u>et al.</u> , <u>Israel J. Chem.</u> (1968) Fe/CEC	30 June 67
14	x	x	Jackson, <u>ISSS 9th Congr.</u> (Adelaide) (1968) pH/CEC	1 July 67
15	x	x	Dolcater <u>et al.</u> , <u>SSSA Proc.</u> (1968) CES/mica-verm layer charge	15 Dec 67
16	x	x	Syers <u>et al.</u> , <u>Geochim. Cos. Acta</u> (1968) Quartz Isolation by H ₂ SiF ₆	14 Feb 68
17	x	x	Mokma <u>et al.</u> , <u>SSSA Proc.</u> (1970) Muscovite flakes/CEC, coatings	27 Feb 70
18	x	na	Technical Progress Report (1968)	24 Feb 68
19	x	na	Science Information Exchange form	24 Feb 69
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COO-1515 Ms.	Sent		Author, Journal, Content	Manuscript date
	Re-print			
21*	x	x	Rex <u>et al.</u> , <u>Science</u> (1969) Aerosolic dust/fission	23 Sept 68
22	x	x	Syers <u>et al.</u> , <u>S. Sci.</u> (1969) Dusts/loess/fission	20 Feb 69
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25	x	x	Dolcater <u>et al.</u> , <u>CCMin</u> (1970) CEC/Ti Subst.	27 Feb 70
26	x	na	Technical Progress Report (1969-70)	28 Feb 70
27	x	x	Jackson <u>et al.</u> , <u>SSSAProc</u> (1971) dusts/geomor.	26 Feb 71
28	x	x	Syers <u>et al.</u> , <u>S. Sci.</u> (1972) dusts/ ¹³⁷ Cs	26 Feb 71
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32	x	x	Mokma <u>et al.</u> , <u>J. S. Sci.</u> (1972) Eol./S. Pac.	26 Feb 71
33	x	x	Mokma <u>et al.</u> , <u>J. S. Sci.</u> (1973) ASL/Isotopes	26 Feb 71
34	x	x	Jackson <u>et al.</u> , <u>SSSAProc.</u> SEM/Verm (1973)	26 Apr 72
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37	x	x	Sridhar <u>et al.</u> , <u>Am. Min.</u> Blisters/cations (1972)	26 Apr 72
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39	x	na	Science Information Exchange Form (1971)	6 Feb 71
40	x	na	Science Information Exchange Form (1972)	6 Apr 72
41	x	na	Technical Progress Report (1971-2)	26 Apr 72
42	x	xx	Sridhar <u>et al.</u> , <u>CCM</u> Blisters/fixing cations (1973)	5 Aug 72
43	na	x	Jackson <u>et al.</u> , <u>Geoderma</u> (1972) ASL/Isotopes	4 Sept 72
44	xx		Lee <u>et al.</u> , <u>CCM</u> Weathering mica domains	10 July 73
45	x		Lee <u>et al.</u> , <u>SSSAP</u> ²³⁸ U Fission tracks (1974)	29 Oct 72
46	x		Veith, Jackson, <u>CCMin</u> Layer charge change	4 Sept 72
47	x	na	Technical Progress Report (1972-3)	6 Apr 73
48	xx		Jackson/Sridhar, <u>SSSAP</u> Scan EM/Verm weathering	2 Nov 73
49	x	xx	Jackson <u>et al.</u> , <u>Soil Sci.</u> Global dusts (1973)	4 May 73
50	x	na	Science Information Exchange Form (1973)	16 Apr 73
51	xx		Lee <u>et al.</u> , <u>SSSAP</u> Mica Verm/ultramicrotomy	10 Aug 73
52			Kinniburgh <u>et al.</u> , <u>SSSAP</u> Transition metal sorption	In preparation
53	xx		Churchman <u>et al.</u> , <u>J.Geophys.R.</u> Source eolian	30 Apr 74
54	xx		Jackson ISSS 10th Cong (Moscow) Eolian addition (1974)	1 May 73
55	xx		Sridhar/Jackson <u>SSSAP</u> Layer charge decrease	12 Nov 73
56	xx	na	Technical Progress Report (1971-74)	29 Apr 74
57	xx	na	Science Information Exchange Form (1974)	29 Apr 74

*Numbers refer to published papers, Technical Progress Reports, and Science Information Exchange Form.

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<u>Sent</u>			
C00-1515 Ms. print	Re-	Author, Journal, Content	Manuscript date
58*		Henderson <u>et al.</u> <u>CCM</u> Verm-CaCO ₃	In preparation
59		Sridhar <u>et al.</u> <u>SSSAP</u> Isotopic ratio/source	In preparation
60		Jackson, Lee, Brown <u>CCM</u> Chlor-mica/ultramicrot.	In preparation
61		Lee, Jackson <u>SSSAP</u> Fission particle/layer charge	In preparation
62		Gillette, Sridhar <u>et al.</u> Isotopic tracing of dust	In preparation
63		Clayton, Sayin <u>et al.</u> Detrital mixed reservoir	In preparation
64		Kinniburgh, Jackson, Radioactive Ca,Zn sorption on Fe oxide	In preparation
65			
66			
67	na	Technical Progress Report (1974-75)	27 Apr 75
68	na	Science Information Exchange Form (1975)	27 Apr 75

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0.25 man-year equivalent, for 12 months (25% of time in year to date, and to end of current term of contract)

Co-Investigator, Philip A. Helmke

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