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EOLIAN DUST AS A FACTOR IN SOIL DEVELOPMENT ON THE PAJARITO PLATEAU, LOS ALAMOS AREA, NORTHERN NEW MEXICO

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Abstract—Soils atop the Pajarito Plateau in northern New Mexico are variable with respect to degree of development and profile characteristics. This study focuses on the impact of eolian dust in the development of a clay-rich soil on the Bandelier Tuff. A constitutive mass-balance (CMB) model was used to assess the impact of dust accumulation. To identify an immobile constituent for use as a strain indicator, isoconcentration (isocon) plots were constructed for each illuvial B horizon and for the subjacent R horizon. The isocon plots suggest that Zr and Al are immobile in the solum. These constituents are, however, likely to be present in dust and so, if dust *is* a factor, are not immobile. The overall compositional similarity of the parent Bandelier Tuff to the continental crust makes it difficult to identify admixed dusts via the isocon method. To resolve this problem, Gresens-type equations (two-component mixing models) for a pair of constituents thought to be refractory with respect to chemical weathering, *viz.*, Ti and Zr, were simultaneously solved for the dust fraction present in the illuvial B and R horizons. Compositional data for a post-Archean shale composite were assumed to represent eolian dust. Calculated dust fractions are consistent with the results of particle-size distribution analyses and decline with depth in the study soil. The calculated dust fractions permit correction of the measured Zr level and use of Zr as a strain indicator. The dust-corrected CMB model indicates that dust incorporation is a major component of soil development on the Pajarito Plateau and that Si and alkali removals are more closely balanced and Al, Fe, Ti, Zr, Ca, Sr and Ba are more enriched by eolian addition than indicated by the uncorrected CMB model. The modeling exercise shows that the study soil is not the result of processes associated with production of spodic horizons. Moreover, soil-forming processes at this location seem to reflect the long-term effects of semi-arid to sub-humid climates.

INTRODUCTION

Numerous workers have demonstrated that incorporation of eolian dust influences soil development in arid and semi-arid regions (e.g., Gile, 1970; Gile et al., 1981; McFadden and Weldon, 1987; McFadden, 1988). This relationship is less clearly established, however, for less arid areas, such as the upper portions of the Pajarito Plateau in New Mexico (for climatic data see Bowen, 1990). The Pajarito Plateau comprises a set of gently-sloping, eastward-inclined mesas that are dissected by steep-sided, west- to east-trending canyons. The mesas are predominantly underlain by the 1.4 Ma (Izett et al., 1981, Heiken et al., 1986) Bandelier Tuff. The Plateau includes three principal soil–landform settings—gently sloping mesa tops, steep slopes of the canyon walls, and alluvium-containing canyon bottoms (Watt, 1996). This study focuses on a soil located within the first of these settings.

Soil-geomorphic relations in this area are complex. In general, however, the most strongly developed soils are located on the mesa tops; terraces and canyon bottoms, as a rule, host less well developed soils (Watt, 1996; for exceptions, see McDonald et al., this volume). The mesa-top soils contain abundant clay and citrate-dithionite-bicarbonate-extractable iron; elevated levels of these constituents are consistent with a suite of strongly developed properties (e.g., color, structure) that can be observed in the field (Watt, 1996).

Alluvium derived from the Bandelier Tuff is the predominant parent material for the mesa-top soils (Watt, 1996). The Bandelier, by definition, contains a large glass component; the susceptibility of glass to chemical weathering and the relatively moist climate of the upper portions of the Pajarito Plateau raise the possibility that soil properties in the mesa-top soils are an effect of chemical alteration rather than of eolian dust incorporation. The latter process dominates soil formation throughout the western United States (Birkeland, 1984).

At lower and more arid altitudes, the effect of dust incorporation can be easily recognized in the accumulation of pedogenic calcium carbonate. In fact, levels of this parameter can be used to estimate the magnitude of eolian dust incorporation (McFadden, 1982; McFadden and Tinsley, 1985, Quade et al., 1995).

The purpose of this paper is to demonstrate an approach whereby chemical parameters can be used to assess the magnitude of eolian dust incorporation in soils that lack a strong carbonate component. We use the calculated dust fraction to evaluate the study soil's chemical evolution using a constitutive mass-balance approach.

THE STUDY SOIL

The soil profile examined for this study is located in Technical Area 69 (TA-69) within the Los Alamos National Laboratory (LANL) (see Watt, 1996, for precise location). The study site was selected, at least in part, because the profile was exposed within a trench that had already been excavated as part of an ongoing unsaturated-zone water-balance investigation. Soil-stratigraphic relations at TA-69 are complex (Watt and others, 1994a,b). Earlier workers had implied that most Pajarito Plateau soils are developed within the Bandelier Tuff (e.g., Nyhan, 1978), but the soils at TA-69 are developed within an alluvial parent material that lies uncomformably atop the Bandelier Tuff and consists predominantly of reworked Bandelier and, to a lesser extent, other volcanic units that are exposed in the Jemez Mountains. The illuvial B (2Bt1b, 2Bt2b, and 2Bt3b) and R horizons comprise a buried soil; an overlying fine-grained stratigraphic unit, which we interpret to be eolian loess, is the parent material for a superimposed, weakly developed soil (horizons A and Bw, Tables 1, 2). Vegetation at the study site is dominated by grasses and Ponderosa pines; the elevation is approximately 7300 ft above mean sea level, and the slope is 5 to 7°.

We characterized the study soil using both field and laboratory analyses (Tables 1, 2). The study profile was also characterized using x-ray fluorescence (XRF). Instrumental neutron activation analyses (INAA) for the upper Bandelier Tuff were provided by D. Broxton of the LANL (personal commun., 1994). All chemical analyses (Tables 3, 4) for soils were performed for the less than 2-mm size fraction. A teflon sieve was used during size fractionation to reduce the possibility of contamination of the samples by iron.

IDENTIFICATION OF IMMOBILE CONSTITUENT(S)

Constitutive mass-balance models have been used by numerous workers (e.g., Brimhall and Dietrich, 1987; Brimhall et al., 1988; Chadwick et al., 1990) to identify the coupled mechanical behavior and gain and loss of chemical constituents during alteration of natural systems. The mathematical underpinnings of constitutive mass-balance modeling have been discussed by Brimhall and Dietrich (1987).

Use of constitutive mass-balance models requires identification of immobile chemical constituents to serve as volumetric strain indicators. To determine which, if any, chemical constituents have been immobile in the study soil, we tested the isocon approach of Grant (1986). Isocon diagrams are a graphical solution to the chemical mass-balance equations of Gresens (1967); in the diagrams, element and/or oxide levels in an altered geologic material are plotted against their corresponding values in the material's unaltered equivalent (parent material). Eberly et al. (1994) tested the isocon approach to evaluate elemental mobility in the Pajarito Plateau study soil. Condie et al. (1995) used the method to examine the behavior of rare earth elements in a weathering profile in a granodiorite in Colorado. Other workers (e.g., Olsen and Grant, 1991;

TABLE 1. Field description for the TA-69 study soil.

Depth (cm)	Horizon	Color wet/dry	Structure	Consistence	Texture	Clay Films	Pores	Roots	Efferve-scence	Boundaries
0-14	A	10YR3/3 10YR6/2	1 m,c sbk	ss, ps	SL	0	2f, ver, t 2m, ver, t	2f, 2m	0	a, s
14-19	Bw	10YR4/3 10YR6/2	2 m,c sbk	ss, ps	SL	0	2f, ver, t 2m, ver, t	2f, 2m, 2co	0	a, s
19-50	2Bt1b	7.5YR4/3 7.5YR5/3	3 m, c sbk	s, p	CL	3 p pf, po, co	1f, ver, t 1m, ver, t	1f, 1m, 1co	0	c, s
50-64	2Bt2b	7.5YR4/6 7.5YR5/3	3 m, c sbk	s, vp	CL	3 p pf, po, cobr	1f, ver, t 1m, ver, t	1f, 1m	0	c, s
64-75	2Bt3b	7.5YR4/4 7.5YR5/4	2 f, m sbk	s, p	CL	2 p pf, po, co	1f, ver, t 1m, ver, t	1f, 1m	0	c, s
75 plus	R	7.5YR6/3								

Key–Structure: 1,2,3=strength of development, f=fine, m=medium, c=coarse, sbk=subangular blocky; Consistence: s=sticky, ss=slightly sticky, ps=slightly plastic, p=plastic, vp=very plastic; Texture: SL=sandy loam, CL=clay loam; Clay Films: 1,2=increasing relative abundance, p=prominent, pf=ped face, po=pores, co=colloidal stains, cobr=colloidal bridges; Pores: 1,2,3=increasing relative abundance, f=fine, m=medium, ver=vertical, t=tubular; Roots: 1,2=increasing relative abundance, f=fine, m-medium, co=coarse; Boundaries: a=abrupt, c=clear, s=straight.

TABLE 2. Laboratory analysis of samples from the TA-69 study soil.

Depth (cm)	Horizon	Sand (%)	Silt (%)	Clay (%)	pH	$Fe_{(d)}$ (% Fe)	$Fe_{(o)}$ (% Fe_3O_4)	$CaCO_3$ (%)	Bulk density (g/cm^3)
0-14	A	34.2	58.2	7.62	5.38	1.05	0.07	0.82	1.46
14-19	Bw	25.1	63.3	11.6	5.43	0.79	0.02	0.43	1.44
19-50	2Bt1b	21.7	32.2	46.2	6.41	1.30	0.07	0.44	1.89
50-64	2Bt2b	22.2	25.0	52.8	7.15	0.96	0.08	1.02	1.73
64-75	2Bt3b	37.8	31.3	30.8	7.43	0.78	0.09	0.92	1.33

Key: all concentrations in weight percent; $Fe_{(d)}$=citrate-dithionite-bicarbonate-exactible iron; $Fe_{(o)}$=ammonium-oxalate-extractible iron.

TABLE 3. Major and minor element chemistry for the study soil (weight percent).

Horizon	Si	Ti	Al	Fe	Mn	Mg	Ca	Na	K	P
Bw	35.94	0.46	6.15	1.36	0.03	0.31	0.37	1.09	1.52	0.03
2Bt1b	29.74	0.39	7.95	3.40	2.00	0.64	5.86	1.10	1.77	0.03
2Bt2b	25.42	0.30	9.84	3.70	1.64	0.75	7.30	1.34	2.02	0.03
2Bt3b	27.73	0.25	9.25	3.51	2.08	0.71	7.02	1.42	2.40	0.03
R	32.28	0.18	8.60	1.68	0.02	0.31	0.39	1.86	2.50	0.03
pink Bandelier	33.48	0.17	8.51	0.72	0.01	0.14	0.62	2.17	2.57	0.04
blue Bandelier	32.83	0.18	8.67	1.23	0.00	0.30	0.40	2.24	2.49	0.03
Upper Bandelier	35.63	0.08	7.28	0.98	0.03	0.03	0.22	2.46	2.66	0.01
Ave Crust*			8.25							
W U.S.A. dust†			5.97							

*from Taylor (1964), †from Reheis and others (1995)

TABLE 4. Trace element chemistry for the study soil (parts per million). All soil data by XRF.

Horizon	Rb	Sr	Zr*	Zn	Cu	Co	Cr	Ba	Y	Nb
Bw	8.30	13.80	4.53	4.60	0.70	1.10	3.60	8.66	2.60	2.90
2Bt1b	10.10	11.10	3.20	6.90	1.50	1.60	5.40	6.75	3.90	3.00
2Bt2b	9.70	11.60	2.96	8.30	1.80	1.80	3.20	6.47	2.10	5.00
2Bt3b	10.10	2.50	2.37	8.50	1.30	1.50	3.40	6.16	2.10	4.80
R	9.40	7.40	2.55	7.10	0.90	0.80	1.00	7.85	3.60	4.60
pink Bandelier	6.50	9.70	3.03	4.20	4.40	0.60	2.10	6.06	1.10	5.50
blue Bandelier	7.80	9.50	2.98	5.40	5.90	0.80	1.30	6.71	1.20	5.30
Upper Bandelier (XRF)	10.33	3.18	2.35	5.83				1.58	4.14	5.48
Upper Bandelier (INAA)	10.61		2.39	4.94		0.12	0.39	1.91		
Ave. Crust†			1.65							
W U.S.A. dust‡			1.79							

*Zr value divided by 100, †from Taylor (1964), ‡from Reheis and others (1995)

Selverstone et al., 1991) have used the method to study the alteration behavior of rocks at higher temperatures.

Immobile elements will plot on the isocon diagram along a line (the isocon) described by the relation

$$C^a=(M^o/M^A)C^o,$$

where C^a=the concentration of the *immobile* constituent in the altered material; C^o=the concentration in the parent material; M^o=the reference mass of the original sample; and M^A=the mass after alteration. Any convenient concentrational unit(s) may be employed in the construction of an isocon diagram, and units may be mixed within a given diagram—e.g., weight percent for major and minor elements and parts per million for trace elements. Elements that have been gained by a rock or soil will plot above the isocon; elements that have been lost will plot below.

The isocon diagrams for the 2Bt horizons from the TA-69 soil are shown in Figure 1. Because the study soil is developed in alluvium derived primarily from the Bandelier Tuff, we use the tuff as a proxy for the soil's parent material or unaltered equivalent.

Al and Zr are nearly colinear in each of the diagrams, a relationship consistent with the observation that these elements are, under most conditions, refractory to weathering (Sposito, 1989). In addition, the elemental losses and gains indicated by the isocon diagrams are consistent with those one would expect for this system. For example, the diagrams indicate that Fe and Ca have been added to the TA-69 soil. The Bandelier tuff has only a small amount of Fe and Ca; consequently, introduction of a dust component would probably strongly enrich these components. Conversely, leaching of the profile by aqueous solutions would produce the observed loss of alkali metals.

Eolian dust, however, is derived from the earth's crust, and Al and Zr are likely to be important components of such air-borne material. If so, and if dust incorporation is an important process on the Pajarito Plateau, Al and Zr are unlikely to be immobile—they are being *added* to the system. It is important to ask, therefore, whether addition of eolian dust to a rhyolitic parent material could be detected using the isocon method. To do so, we tested the effect of admixing three distinct materials—average continental crust (Taylor, 1964), modern eolian dust from the western U.S.A. (Reheis et al., 1995), and the loessial Bw horizon from the study soil. We calculated "isocon" diagrams that show the effect of adding 30 wt% of the three proxy materials to an alluvium identical in composition to the Bandelier Tuff (Fig. 2). Based on the actual isocon diagrams for the 2Bt horizons, Al and Zr concentrations for the proxy materials (Tables 3, 4) and for the upper Bandelier Tuff were used to calculate the dust-affected isocons.

In each case, admixture of 30 wt% allochthonous material through incorporation of eolian dust would produce an effect that would be in-

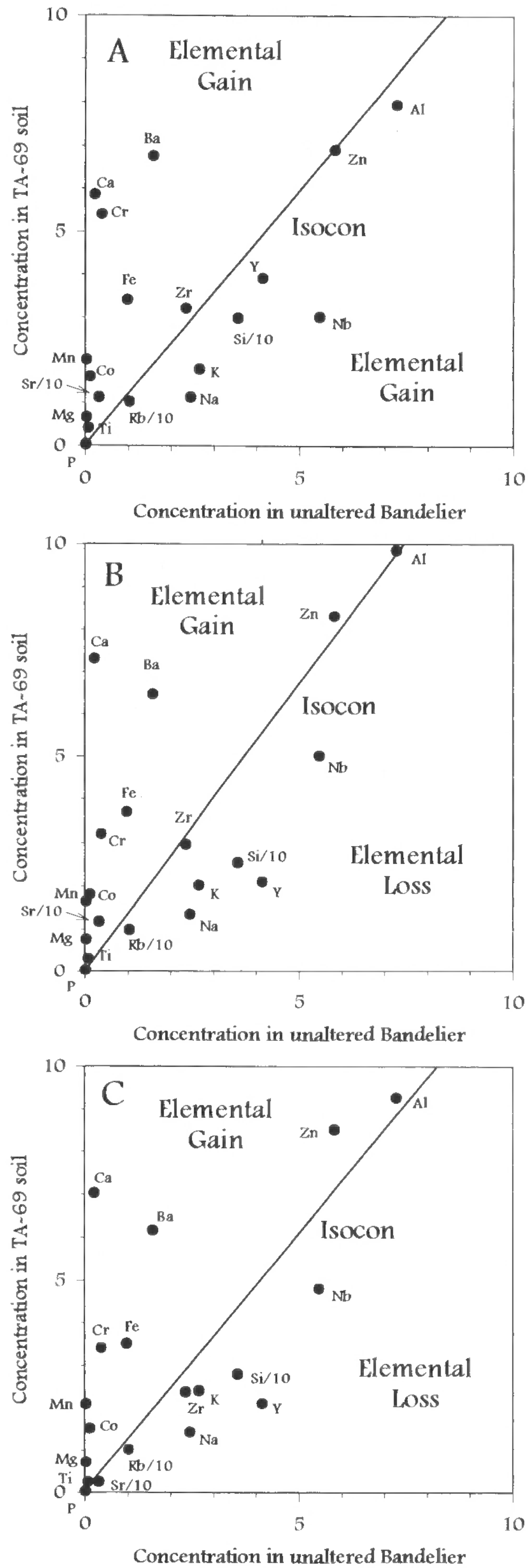

FIGURE 1. Isocon diagrams for the TA-69 study soil. A, 2Bt1b horizon. B, 2Bt2b horizon, C. 2Bt3b horizon. Major and minor elements are in weight percent, trace elements are in parts per million.

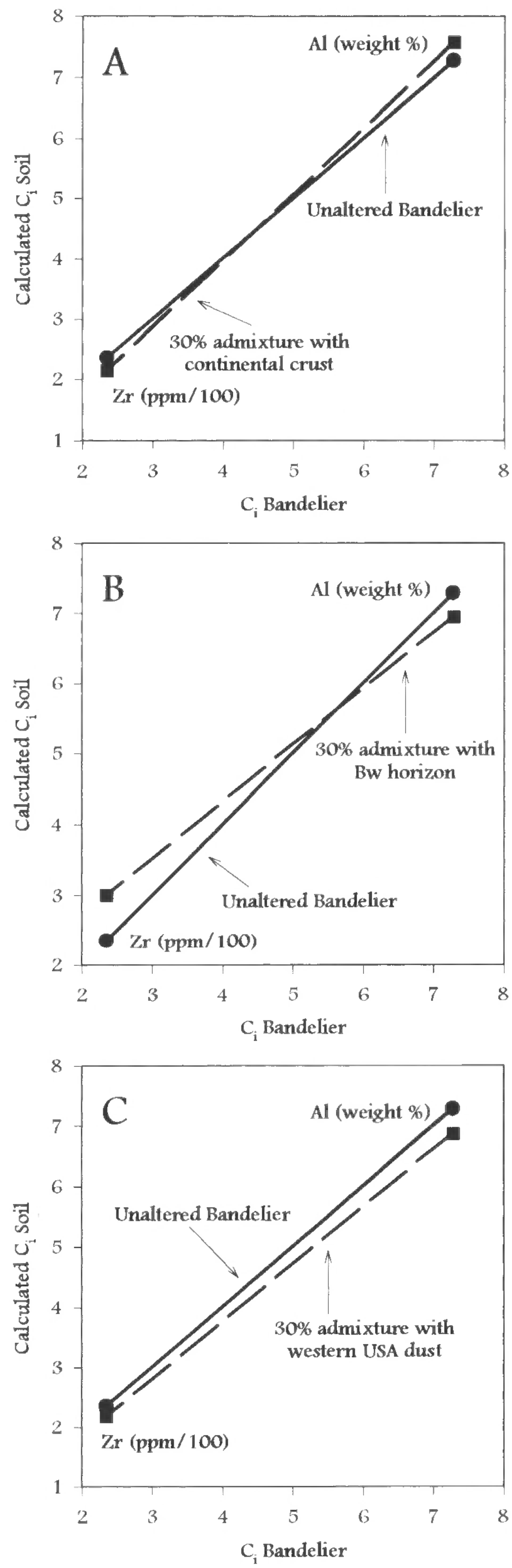

FIGURE 2. Calculated Al-Zr isocon diagrams showing soil development as a function of eolian dust accumulation. Parent material is an alluvium with a composition equal to that of the Bandelier Tuff. A, Admixture of Bandelier and continental crust of Taylor (1964). B, Admixture of Bandelier and Bw horizon from the study soil. C, Admixture of Bandelier and western U.S.A. dust, from Reheis et al. (1995).

distinguishable from those caused by chemical weathering and analytical error. Mathematically, this relatively undramatic effect is an artifact of the compositional similarity of the Bandelier (or, indeed, of any rhyolite) to the earth's crust. Admixture of continental crust or of most materials derived from the crust by weathering will produce a negligible change in the isocon.

The largest effect is produced by admixture of the Bw horizon from the study soil. This material, however, is a loess and, thus, is the result of a distinct depositional event—the unit, therefore, could easily be compositionally unique. Thus, there is no reason to believe that the loess at TA-69 is compositionally representative of the eolian dusts that have been incorporated by the parent alluvium since the time of its deposition.

This inability to easily recognize important contributions of eolian material by using chemical data makes it more difficult to use given constituents as strain indicators for CMB modeling. Brimhall et al. (1988) used zirconium as a strain indicator evaluating the eolian contribution of this constituent by isolating zircons and studying them microscopically. Zircons of eolian derivation were texturally distinguishable from those related to the parent material. Because the parent material of the TA-69 soil is an alluvium, however, many autochthonous zircons may be rounded, making application of such a technique difficult.

This problem may be addressed through simultaneous solution of the Gresens (1967) equation for two immobile constituents—in this case, titanium and zirconium. These elements are commonly immobile in the weathering environment (Sposito, 1989). The Gresens' (1967) equation for titanium, as "refined" by Grant (1986) is

$$C_{Ti}^{A} = \frac{M^{\circ}}{M^{A}} (C_{Ti}^{O} + \Delta C_{Ti})$$

where C° and C^A are the pre- and post-alteration concentrations of the subscripted components, respectively; M° is the reference mass of the original sample; M^A is its mass after alteration; and ΔC is the change in mass of the subscripted component divided by M°.

The resulting, simultaneously solved equation for titanium and zirconium may be arranged to permit calculation of the fraction of the soil that is attributable to incorporation of eolian dust:

$$F_{dust} = \frac{\dfrac{C_{Ti}^{P} C_{Zr}^{S}}{C_{Zr}^{P}} - C_{Ti}^{S}}{\dfrac{C_{Ti}^{P} C_{Zr}^{D}}{C_{Zr}^{P}} - C_{Ti}^{D}}$$

where C's are concentrations in arbitrary (but identical) units; superscripts P, S and D denote parent material, soil, and dust, respectively; and F_{dust} is the mass fraction of eolian dust incorporated in the soil.

The equation contains three unknowns, *viz.*, F_{dust} and the concentrations of titanium and zirconium in the dust phase. It may be solved approximately if the dust composition can be estimated. To do so, we used the post-Archean shale composite of Taylor and McClennan (1985). Use of this material to represent eolian input on the Pajarito Plateau represents a major assumption, but the shale composite reflects the integrated composition of the fine-grained materials that are removed from the continental crust by weathering and, so, must be at least *similar* chemically to eolian dust. The equation was used to calculate dust fractions for the horizons of the study soil. Dust contents (F_{dust}) for the various horizons are 2Bt1b, 53%; 2Bt2b, 37%; 2Bt3b, 32%; and R, 17%.

CONSTITUTIVE MASS-BALANCE MODELING

Constitutive mass-balance models (Brimhall and Dietrich, 1987) provide a quantitative framework for examining the depletion or enrichment of elements in geologic materials during alteration. The governing equation (Brimhall et al., 1988) is

$$\frac{C_{j,w}}{C_{j,p}} = \frac{\rho_p}{\rho_w} \left(\frac{1}{\varepsilon_{j,w}+1}\right) + \frac{100 m_{j,influx}}{C_{j,p}\, \rho_w\, B_w}$$

where $C_{j,w}$ is the concentration of element j after weathering, $C_{j,p}$ is the concentration of element j in the parent material, r_w is the density of the

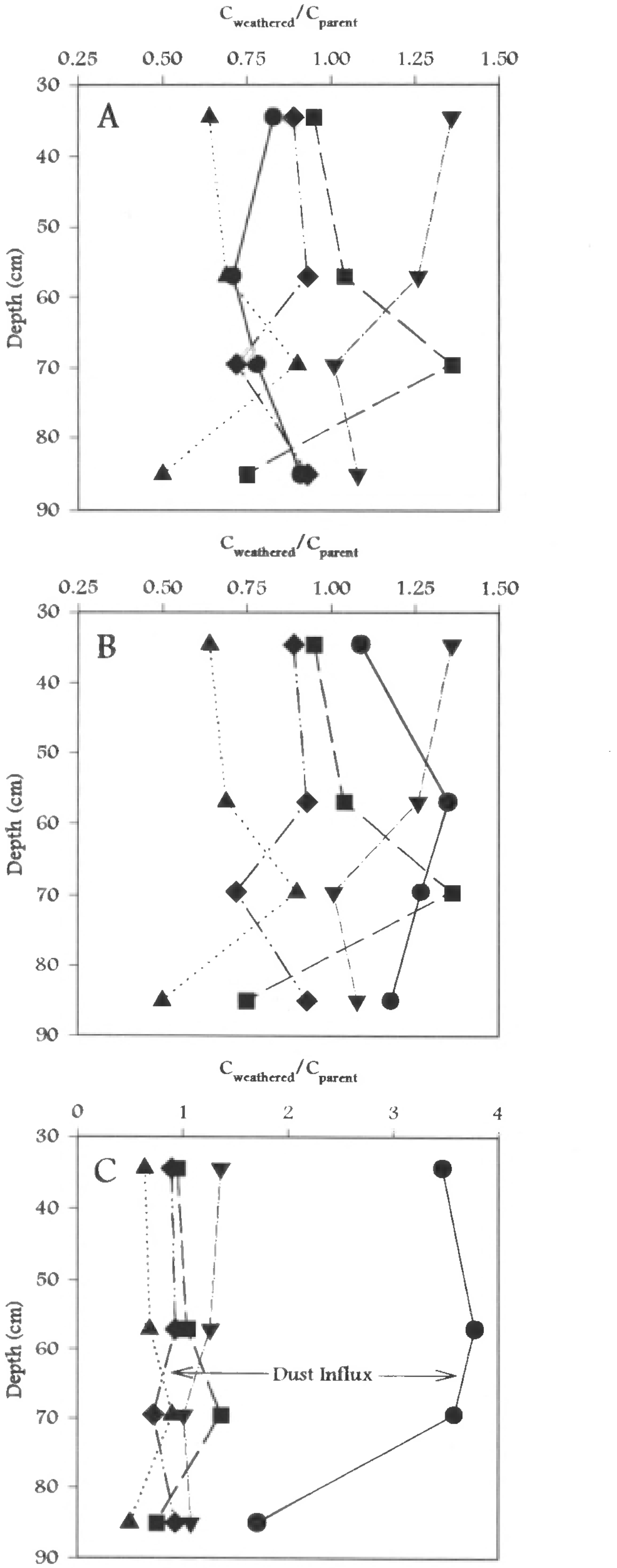

FIGURE 3. Constitutive mass-balance model for A, Silicon; B, Aluminum; C, Iron. Circles, measured ratio; squares, maximum residual enrichment; upward triangles, minimum residual enrichment; downward triangles, uncorrected strain plus residual enrichment; diamonds, dust-corrected strain plus residual enrichment.

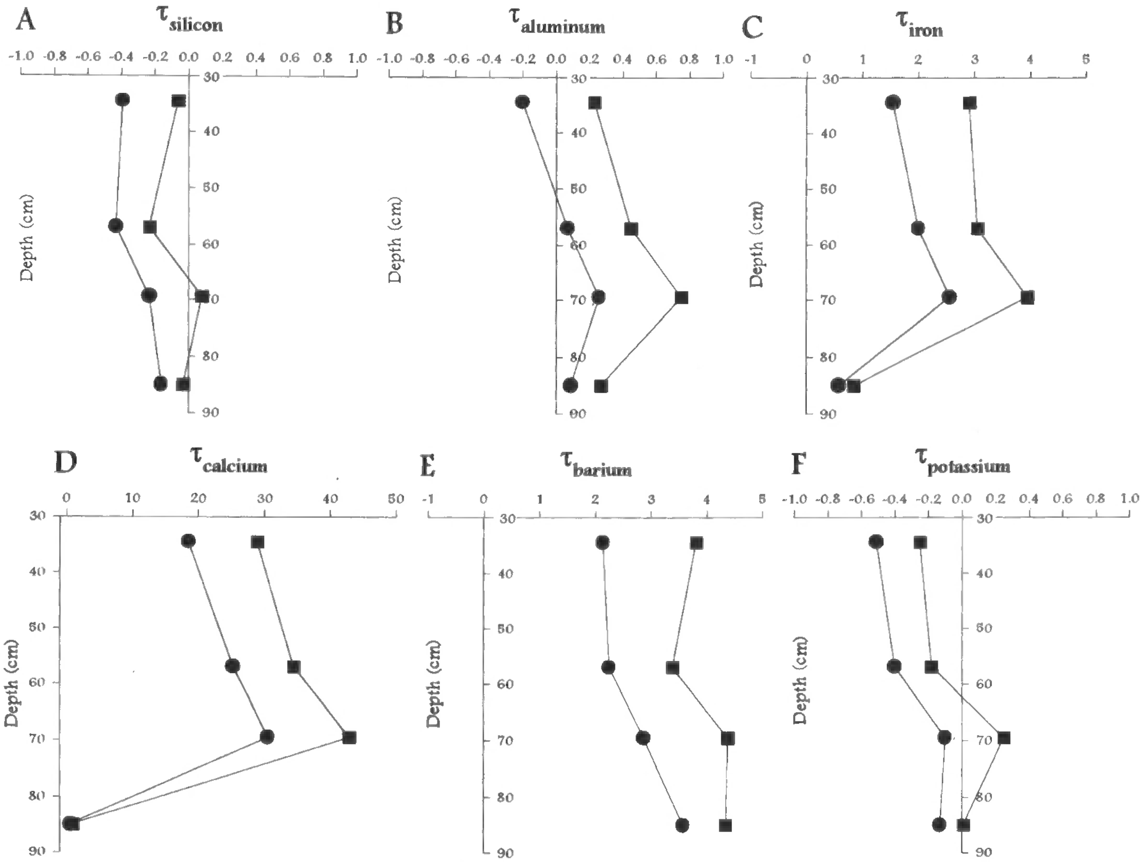

FIGURE 4. τ diagrams for the study soil. A, Silicon; B, Aluminum; C. Iron, D, Calcium; E, Barium; F, Potassium. Circles represent calculations with no correction for dust influx. Squares represent calculations with correction for dust influx.

weathered material, r_p is the density of the parent material, $e_{i,w}$ is the strain due to weathering, and $m_{j,influx}$ is the mass of element j added (or removed) to (or from) an elementary volume with height equal to B_w during weathering. Concentration terms in this equation are on a mass per mass basis. The first term on the right-hand side represents closed-system behavior—i.e., residual enrichment and changes in composition due to alteration-related volumetric change—that is, strain. The second term represents open-system behavior—i.e., actual addition or subtraction of components via illuviation (including illuvial transport of material introduced as dust) or solute transport.

Volumetric strain is calculated based on comparison of compositional data for an immobile component in the altered material of interest versus data for that component in the parent material. To calculate the strain, we corrected the zirconium data for the portion of that component that was introduced by incorporation of eolian dust.

The uncorrected CMB model indicates that silicon (Fig. 3A) is depleted beyond the level produced by residual enrichment and strain in the study soil. Silicon levels are well accounted for by the dust-corrected model, however, with significant depletion only in the 2Bt2b (datum at 57 cm depth) horizon.

The dust-corrected model indicates that aluminum (Fig. 3B) is considerably more enriched than indicated by the standard (uncorrected) CMB model. In the corrected model, enrichment occurs in every horizon; this enrichment is probably related to addition of aluminum via incorporation of aluminosilicate minerals as eolian dust.

This effect is even more pronounced for iron (Fig. 3C). The wide disparity between calculated concentration ratios using the dust-corrected model and the measured values indicates significant addition of iron-containing materials by incorporation of eolian dust.

The open-system component of the study soil's evolution can be highlighted by means of the function τ, a solution of the basic CMB model in terms of the mass influx of some element of interest divided by the mass of that element present in the parent material (Brimhall et al., 1988).

$$\tau_{j,w} = \frac{100 m_{j,influx}}{C_{j,p}\,\rho_p\,B_p} = \frac{\rho_w\,C_{i,w}}{\rho_p\,C_{i,p}}(\varepsilon_{j,w}+1)-1$$

where all terms are as defined above.

The dust-corrected τ function for silicon (Fig. 4A) indicates that element is less depleted from the horizons of the study soil than would be concluded from examination of the uncorrected data. Silicon may, in fact, be slightly enriched in the 2Bt3b horizon. Similar relations hold for potassium (Fig. 4F).

Aluminum, iron, calcium, barium, strontium, titanium, and zirconium are enriched in each of the horizons of the study soil (Figs. 4B-E, 5B-D). In each case, the dust-corrected CMB model indicates a greater degree of enrichment than is suggested by the uncorrected model. Sodium (Fig. 5A) is depleted in all horizons of the study soil. The uncorrected CMB model, however, indicates greater depletion than can be supported using the dust-corrected calculations. Strontium (Fig. 5B) is dramatically depleted in the 2Bt3b horizon of the study soil relative to levels in the horizons above and below. In fact, $\tau_{strontium}$ is approximately zero, meaning that little strontium has been added to the system in absolute terms. This observation is puzzling because calcium (Fig. 4D) is highly enriched in this horizon, and calcium and strontium typically exhibit similar geochemical behavior. At present, we lack an explanation for this observation.

DISCUSSION AND CONCLUSIONS

The isocon method is typically used to assess gains and losses of elements and to identify immobile constituents in altered geologic materials. For soils developed in materials that are similar in composition to continental crust, however, this technique is not sensitive to influx of eolian materials; high-magnitude (up to 30%) influx will produce negligible displacement or rotation of the isocon line.

The magnitude of dust influx may be quantified if two constituents are considered to be refractory with respect to chemical weathering and resistant to translocation. We judged Ti and Zr to meet these criteria and

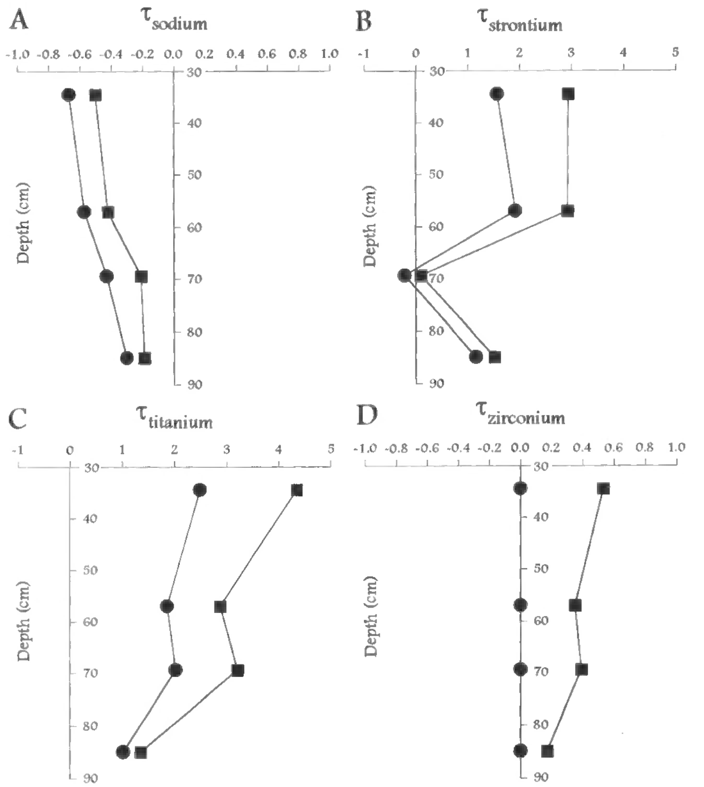

FIGURE 5. τ diagrams for the study soil. A, Sodium; B, Strontium; C, Titanium; D, Zirconium. Circles represent calculations with no correction for dust influx. Squares represent calculations with correction for dust influx.

solved simultaneous Gresens-type equations for these two elements for the fraction of the altered material that was introduced by incorporation of eolian dust. Dust fractions decrease with depth in the soil and are in accord with the results of particle-size distribution analyses.

The dust fraction for each horizon may be used to correct zirconium concentrations, allowing use of zirconium as a chemical strain indicator in constitutive mass-balance equations. Comparison of dust-corrected CMB models to uncorrected models shows that silicon was relatively immobile during alteration or (more likely) was present in the dust phase at levels similar to those in the Bandelier Tuff so that addition by incorporation of eolian material did not result in silicon enrichment. The dust-corrected models show that aluminum and iron are enriched to levels considerably above those that can be produced by any combination of strain and/or residual enrichment.

The modeling exercise demonstrates, therefore, that dust influx is an important component of soil development atop the Pajarito Plateau. Clearly, given the climate of the Pajarito Plateau, chemical weathering also plays a role in soil evolution, especially during the effectively wetter glacial climates of the Quaternary. Even so, chemical weathering is inadequate to produce the observed chemical changes.

The data clearly demonstrate that these soils are not the product of processes associated with the development of spodic horizons, as has been suggested for the mesa-top soils by Nyhan (1978). In particular, soil pHs (Table 2) and elevated levels of bases (Fig. 4, 5) are inconsistent with the types of leaching phenomena that produce spodosols.

Soils in more arid environments contain pedogenic carbonate that is demonstrably related to eolian dust influx (Gile et al., 1981). This paper shows that southwestern soils of more humid climates such as that of the Pajarito Plateau are also profoundly impacted by incorporation of eolian dust.

The profile at TA-69 comprises a weak upper soil developed in a loessial deposit that is predominantly of eolian derivation and a more strongly developed soil developed in alluvium derived largely from the Bandelier Tuff. Because soil-forming processes in the older, buried soil are demonstrably dominated by influx of eolian dust, semi-arid to sub-humid climates have likely influenced soil development at this location throughout most of the late Quaternary.

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