

ity decrease of about 15 percent with respect to regional velocity. An important feature of the model is a core region beneath Mount Hannah and the steam-production zone where a 25 percent decrease in velocity is required to satisfy the data (shaded area in Fig. 2a). The low-velocity body extends to an average depth of 10 to 15 km, with the core regions extending to 20 km or more. The shape of the low-velocity body is not well defined, and there are thus deficiencies in our modeling procedure.

A reduction of the compressional seismic wave velocity within the earth can be due to a variety of factors (7). However, geologic and other geophysical data support our observations and indicate the presence of a magma body under the Clear Lake volcanic field. Chapman (3) has suggested the possibility of a magma chamber under Mount Hannah to explain the large gravity low in the region. Isherwood (4) inverted gravity and aeromagnetic data to model a magma chamber 10 to 15 km in diameter under Mount Hannah. Hearn *et al.* (2) have also shown that geologic and geochronological evidence strongly support the hypothesis that an active magma chamber may be present under the Clear Lake volcanic field. The attenuation of teleseismic body waves (5) and the shallow seismicity (14) are other geophysical observations that lend support to the magma chamber hypothesis. We propose, therefore, that the low-velocity body under Mount Hannah represents rock in a state of partial melting. Unfortunately, few laboratory data exist to make possible an estimation of the degree of partial melting from seismic data. Even a theoretical model, such as that proposed by Walsh (16) in which partial melting occurs in randomly oriented penny-shaped cracks, requires knowledge of both P- and S-wave velocity and attenuation to obtain this estimate.

It is possible that the dry-steam reservoir associated with The Geysers may be responsible for some of the P-wave delays observed in that zone. Laboratory data by Nur and Simmons (17) show that the compressional velocity in dry, porous rocks is significantly lower than in the fluid-saturated condition. However, the seismic refraction survey of Majer and McEvilly (12) at The Geysers does not show a sufficient velocity anomaly in the top 3 km to account for the observed teleseismic delays. Thus, any delay attributed to the dry-steam field must be occurring at depths greater than 3 km, necessitating that the fracture system extend to about 20 km. Alternatively, the magma chamber postulated to be

beneath Mount Hannah may extend beneath The Geysers and together with an overlying fracture system may be responsible for the observed delays. The strong azimuthal variation of delays at stations near The Geysers (Fig. 1) also suggests that an anisotropic velocity distribution in either the fractured dry-steam system or within the magma body may be present. Walsh (18) has shown that the compressibility of rocks with cracks is anisotropic. However, since the maximum velocity decrease occurs along a plane perpendicular to the direction of crack orientation and since the teleseismic waves travel at an angle to the vertical of about 20°, a complex fracture model will be required.

A significant feature of our model is a core region in which the velocity decrease may be as high as 25 percent. Data from other areas of Quaternary volcanism such as Yellowstone National Park, Wyoming, and Long Valley, California, show the existence of magma chambers requiring 10 to 15 percent velocity contrast (7, 8). Whether the higher velocity decrease postulated at Mount Hannah means that the magma chamber in this locality is in a higher state of partial melt than that under Yellowstone or Long Valley cannot be determined until shear wave velocity and attenuation data are collected.

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Acid Rain: Neutralization Within the Hubbard Brook Ecosystem and Regional Implications

Abstract. *The neutralization of strong acids from precipitation is largely accomplished (75 percent) in the soil zone by rapid reaction with basic aluminum salts and biologic matter. On a regional basis, acidified and aluminum-rich lakes and streams in New England are confined mainly to low-order watersheds.*

The phenomenon of excess strong acids in contemporary precipitation ("acid rain") over the northeastern United States, and particularly at the Hubbard Brook Experimental Forest, is well documented (1). The smallest headwater streams of the Hubbard Brook Experimental Forest directly reflect this input of strong acids in terms of their low pH (2). In marked contrast, however, the major trunk streams of the northeastern United States are not excessively acidified (3); their pH is largely dominated by the carbonic acid system, which has

been the norm throughout the geologic past. My purpose in this report is to describe and explain the process by which acid rain is transformed into chemically normal stream water. To this end, the chemical character of a small stream, Falls Brook, has been monitored over a 3-year period. Nine sites along this drainage network (Fig. 1) have been sampled on a monthly basis over three annual cycles. Water samples were collected and chemically analyzed by our standard methods (4). Mean concentration data, averaged over 37 monthly

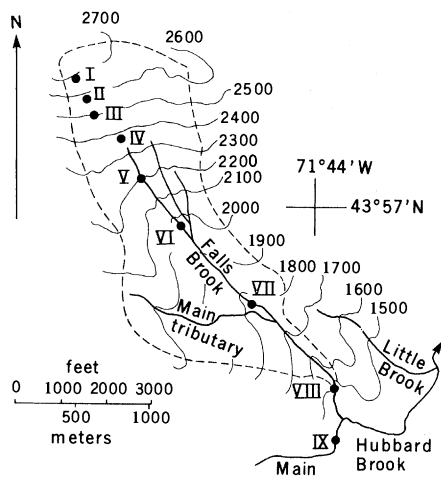


Fig. 1. Plan view of the Falls Brook watershed. The elevations of the various sites are in feet.

samples, show that the ionic strength is essentially constant along the entire length of Falls Brook (Fig. 2A). In marked contrast, however, the qualitative chemistry of Falls Brook systematically changes in the downstream direction (Fig. 2B). In general, the upper reaches of Falls Brook may be characterized as more acid and richer in aluminum than the water downstream.

In Falls Brook, strong acids become successively less important relative to carbonic acid in the downstream direction (Table 1). Bicarbonate alkalinity occurs in detectable amounts in the downstream sections of Falls Brook during very low discharge periods, winter or summer. On the average, however, the acidity of Falls Brook is persistently dominated by acids other than carbonic acid.

The relationship between the acidity and aluminum content of Falls Brook sheds some light on the acid neutralization reaction. Various aluminum hy-

droxide compounds are common and ubiquitous components in the podzolic soils that are characteristic of the Hubbard Brook Experimental Forest. The solubility of these compounds is a sensitive function of pH and varies directly as a power of $[H^+]$. Various inorganic and organic complexes of aluminum are also soluble (5). Dissolved aluminum thus is not usually confined to a single ionic species in the soil zone. As a first approximation to this condition, I assumed that Al^{3+} , $AlOH^{2+}$, and $Al(OH)_2^+$ are present in Falls Brook water in equilibrium with amorphous aluminum hydroxide at the ambient pH (6). Dissolved aluminum in excess of this amount (Table 1) is then assigned to a coexisting monovalent, negatively charged organic complex whose exact composition is unknown.

Several lines of evidence support this kind of distribution of ionic species for aluminum.

1) In the upper reaches of Falls Brook (sites I through III), the measured amounts and the changes in the dissolved aluminum distribution (Fig. 2B and Table 1) conform generally to that expected for a metastable $Al(OH)_3$ compound.

2) At the pH found in the lower reaches of Falls Brook (sites V through IX), aluminum solubility should be negligible (Table 1). Therefore, the bulk of the aluminum observed in solution in these waters must be in a form other than Al^{3+} , $AlOH^{2+}$, or $Al(OH)_2^+$.

3) Micropore filtering ($0.1 \mu m$) of these waters elicits no significant change in the concentration of measured aluminum, thus mitigating against the presence of suspended $Al(OH)_3$ particles or large polymers.

4) The low concentration of dissolved silica for site I (Table 1) indicates that this water is at the boundary of the gibbsite-kaolinite stability field (7). Down-

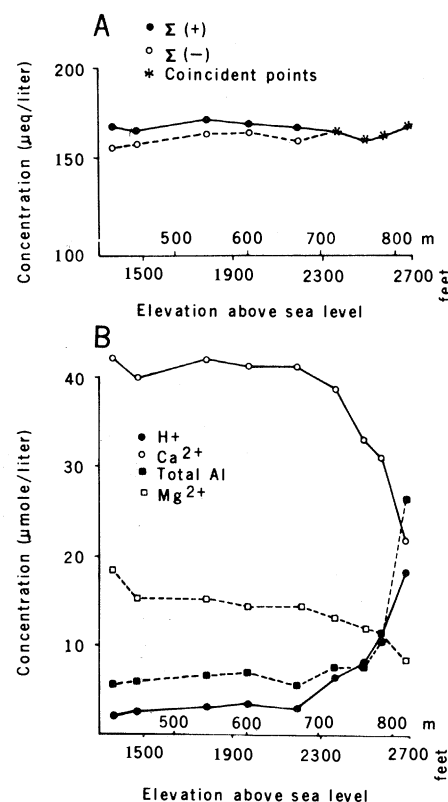


Fig. 2. Chemistry of Falls Brook for the period February 1975 through February 1978. (A) Mean ionic strength along the stream network. (B) Distribution of selected cations as a function of elevation.

stream, the increasing silica concentrations shift the water composition systematically away from the gibbsite stability field and well into the kaolinite stability field. This trend suggests that aluminum solubility plays a role in the ionic composition of upstream waters, whereas chemical weathering reactions dominate the composition of downstream waters.

5) Typical Hubbard Brook stream water contains some 1 to 5 mg of dissolved organic carbon per liter (8). Data from low-order streams of the Adirondacks region suggest that this amount of dissolved organic carbon is sufficient to complex several tens of micromoles of aluminum in a neutral or negatively charged form (9).

Taken together, these arguments suggest that different kinds of aluminum ion species at different points along Falls Brook may be expected and that the good ion balance (Fig. 2A) achieved on the basis of such an assumption is reasonable.

The chemical data from Falls Brook show that the neutralization of acid rain is rapidly and largely (about 75 percent) accomplished in the upper soil or regolith by the dissolution of preexisting aluminum hydroxide compounds and by the leaching of bases from various bio-

Table 1. Acid, aluminum, and silica chemistry of Falls Brook as a function of elevation. Mean chemical data are based on 37 consecutive monthly samples for the period February 1975 through February 1978. The error is expressed as the standard deviation of the mean. Unless otherwise specified, units are micromoles per liter.

Sample site (Fig. 1)	Stream order*	Mean pH	Ionized carbonic acid	Total acid	Total measured aluminum	Al^{3+} , $AlOH^{2+}$, and $Al(OH)_2^+$ saturation	Dissolved silica
I	1	4.73	3.7 ± 0.5	18.3 ± 0.6	26.3 ± 1.1	29.4 ± 1.1	37 ± 2
II	2	4.94	1.5 ± 0.3	11.5 ± 0.9	10.7 ± 1.5	10.9 ± 1.1	90 ± 7
III	2	5.09	1.5 ± 0.2	8.1 ± 0.6	7.8 ± 0.7	5.8 ± 0.5	102 ± 5
IV	2	5.19	2.0 ± 0.2	6.4 ± 0.4	7.8 ± 1.1	4.1 ± 0.3	92 ± 3
V	3	5.54	1.4 ± 0.1	2.9 ± 0.3	5.6 ± 0.4	1.4 ± 0.3	97 ± 3
VI	3	5.46	1.0 ± 0.1	3.5 ± 0.3	7.0 ± 0.4	1.8 ± 0.3	107 ± 3
VII	4	5.51	1.2 ± 0.1	3.1 ± 0.3	6.7 ± 0.4	1.5 ± 0.3	105 ± 3
VIII	4	5.59	1.0 ± 0.1	2.6 ± 0.3	5.9 ± 0.4	1.2 ± 0.3	107 ± 3
IX	5	5.68	0.9 ± 0.1	2.1 ± 0.4	5.6 ± 0.4	1.0 ± 0.4	103 ± 3

*First-order streams are the smallest unbranched tributaries; second-order streams develop at the confluence of two first-order streams; third-order streams, at the confluence of two second-order streams; and so forth.

logic materials (10). Thus, by the time acid rain first appears as stream flow (site I), its acidity has already been greatly diminished, going from 72 μeq of H^+ per liter of average acid rain (2) to 18 μeq /liter (site I in Table 1). Subsequently, further neutralization of the strong acids is effected by chemical weathering reactions with the concurrent loss of dissolved aluminum and the gain of strong bases and silica by the coexisting water (Table I and Fig. 2B). This aged water is in equilibrium with kaolinite and typifies one of the principal water types at Hubbard Brook (11).

Falls Brook is not unique with respect to its distribution of acidity and ion chemistry. The main tributary of Falls Brook (Fig. 1) and another low-order, low-elevation drainage system (Little Brook in Fig. 1) have also been monitored periodically along their lengths. These streams show a pattern of downstream chemical change identical in kind to that obtained in Falls Brook. It appears that the observed chemical changes are not a function of elevation within the watershed but rather a function of stream order, irrespective of elevation. Similarly, investigators have sampled stream networks draining a variety of igneous and metamorphic rock types in New Hampshire and Vermont (12). A pattern of diminishing acidity in the downstream direction has been observed in every case. Falls Brook thus appears to be representative of a more general regional process and effect.

We may thus reasonably infer that the neutralization of acid rain over the granitic and forested terrane of New England is accomplished in low-order watersheds by the two-step chemical process described above. The presence of high concentrations of dissolved aluminum has been reported for acidified waters from a variety of environments including the alpine zone of New Hampshire (13), the Adirondack region (9), and Norway (14). As long as strong acids persist in solution, the neutralization reactions proceed essentially as a base exchange reaction at constant ionic strength (Fig. 2). However, when the strong acids are eventually neutralized, carbonic acid will ionize and the ionic strength of the system may increase through open-system carbonation reactions.

Some of the more general implications of this mode of acid rain neutralization include the following:

1) Hydrologically, the effect of acid rain on stream water quality will be evident mainly in low-order drainage systems, especially where the bedrock is chemically unreactive as in an igneous

and metamorphic terrane. In the marble belts of New England, acid rain neutralization is rapidly accomplished by the solution of carbonate minerals (15). Probably no sustained acidifying effect will be manifested on major streams, regardless of bedrock type.

2) As a consequence, lakes whose watersheds are composed of igneous or metamorphic bedrock and which receive water from low-order streams will tend to be acidified and rich in aluminum. In general, it may be anticipated that alpine and upland lakes will show this effect more than lowland lakes or those that receive mostly aged stream water or groundwater, or both.

3) With respect to soils, the participation of soil aluminum in the immediate acid neutralization process probably dislocates or otherwise disturbs the normal order of soil formation (13). The soil and regolith of the New England landscape are presently acting as a large sump for the absorption of excess strong acidity.

4) Geologically, no excessive chemical weathering activity can be attributed to acid rain over the northeastern United States. The contemporary ionic denudation rate of New England (0.22 eq/m^2) is well below the North American average (0.38 eq/m^2), despite the added component of strong acids washing out over New England (2, 3).

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2-Methyltetrahydrofuran-Lithium Hexafluoroarsenate:

A Superior Electrolyte for the Secondary Lithium Electrode

Abstract. *Rechargeable, high energy density lithium batteries require an efficient lithium electrode. Earlier work with electrolytes based on propylene carbonate, methyl acetate, and tetrahydrofuran yielded poor lithium electrode cycling efficiencies because of electrolyte reduction by lithium. Solutions of lithium hexafluoroarsenate in 2-methyltetrahydrofuran are found to be remarkably stable toward lithium, resulting in cycling efficiencies that approach 98 percent. The ability of 2-methyltetrahydrofuran to resist reduction by lithium is thought to be based on the position of its lowest unfilled molecular orbital relative to that of tetrahydrofuran.*

The development of an ambient temperature secondary battery employing a Li negative has been actively pursued over the past 20 years (1). The key tech-

nical problem precluding the implementation of such batteries is the cycling behavior of the Li electrode. Metallic Li can be plated from organic media con-