



United States
Department of
Agriculture

Forest Service

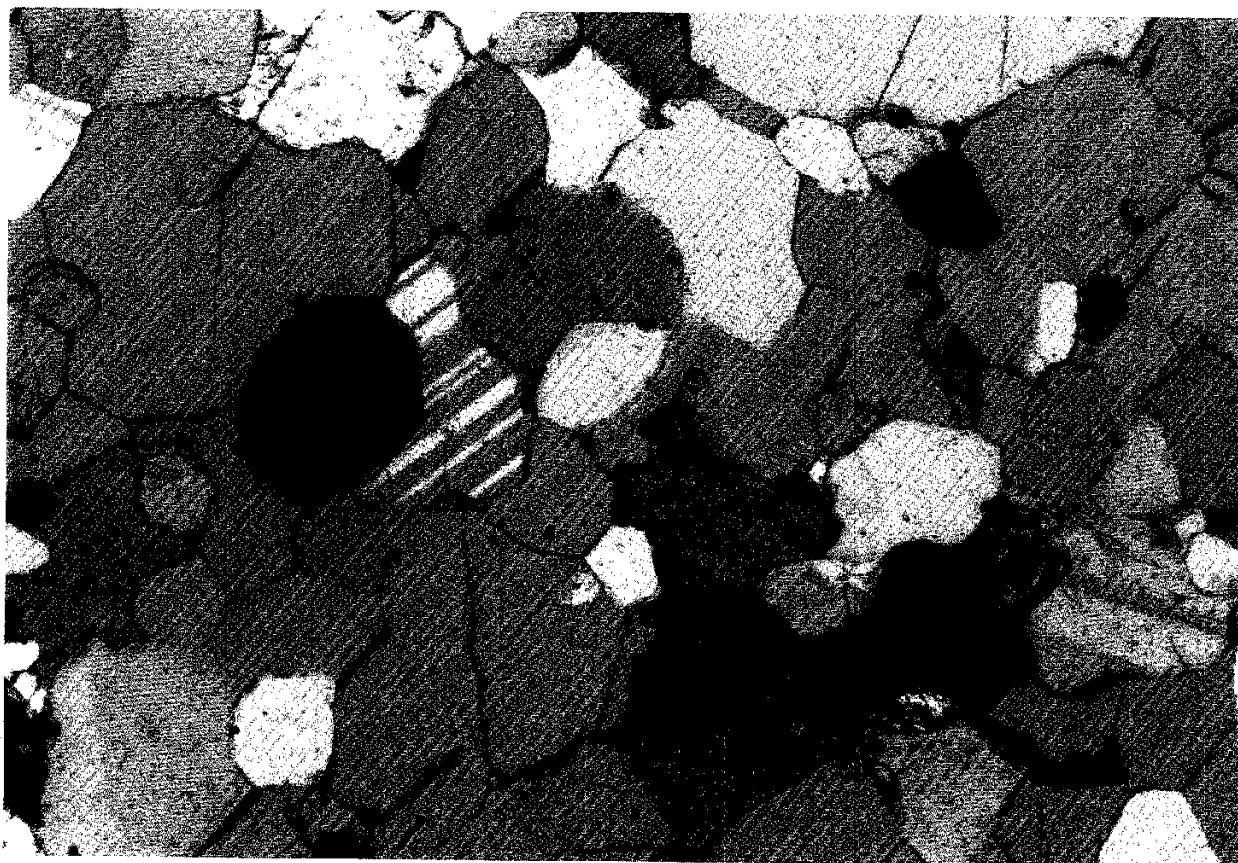
Northeastern Forest
Experiment Station

Research Paper NE-662



Lithologic Composition and Rock Weathering Potential of Forested, Glacial-Till Soils

Scott W. Bailey
James W. Hornbeck



Abstract

Proportions of bedrock lithologies in a wedge-shaped source area were a reasonable model for predicting lithologies present in soils developed on glacial till. Examination of weathering characteristics of rocks collected to verify the model showed substantial staining and pitting of interior surfaces. This information, even though qualitative, can further the understanding of nutrient cycling in forest ecosystems.

The Authors

SCOTT W. BAILEY, Research Geologist, and JAMES W. HORNBECK, Research Forester, are with the Northeastern Forest Experiment Station, Forestry Sciences Laboratory, Durham, New Hampshire.

Acknowledgment

Leon Bailey of Longmeadow, Massachusetts, assisted with the laborious task of sawing rock specimens. Ralph Perron, USDA Forest Service, assisted with sample processing. Kenneth Dudzik, USDA Forest Service, photographed rock specimens. Donald Buso, Institute of Ecosystem Studies, provided valuable suggestions.

Manuscript received for publication 5 August 1991

Cover Photo

A 250x enlargement of a thin section from the Rangeley bedrock formation in central New Hampshire. Thin sections, prepared by slicing rock samples to 30 um thickness, are viewed microscopically to identify minerals. This section shows quartz, hornblende, plagioclase, garnet, and pyrite. Plagioclase (striped mineral left of center) and hornblende (large, darker area in lower right quadrant) are major sources of base cation weathering.

Northeastern Forest Experiment Station
5 Radnor Corporate Center, Suite 200
100 Matsonford Road
P.O. Box 6775
Radnor, Pennsylvania 19087-4585

March 1992

Introduction

Readily available supplies of soil cations such as calcium, magnesium, and potassium are critical for maintaining productive forests. Federer and others (1989) have suggested that some forests in Eastern United States may be experiencing accelerated depletion of calcium due to acidic deposition and intensive harvesting. One effect could be the development of an unfavorable ratio of calcium to aluminum in forest soils, resulting in a decline in tree growth rates (Shortle and Smith 1988). The extent to which this may happen depends on whether calcium contributions from weathering of rocks in geologic parent material and soils will offset depletion rates. Rock weathering is highly variable depending upon lithology, but is the major source of base cations, exceeding atmospheric inputs by several orders of magnitude (Likens and others 1977; Paces 1986).

Unfortunately not much is known about the contributions

of rock weathering to nutrient cycles of forest ecosystems. Usually the only geologic information readily available for forested sites is listed on state bedrock maps that give names and accompanying descriptive material of bedrock lithologies. In glaciated terranes, additional lithologic types deposited in till but derived from off-site sources are seldom considered. The geologic materials in the surficial deposits are probably more important than bedrock in terms of contributing nutrients for forest growth, and buffering forest soils and streams against acidification by atmospheric deposition.

This paper describes methods for predicting lithologies present in soils developed on glacial till, and the potential weathering contributions from rock particles >2 mm in diameter. The methods are not quantitative in terms of providing weathering rates, but they provide information that can further the understanding of forest nutrient cycles, and possibly assist with decisions about forest harvesting.

The Study Area

Our methods were developed and tested on a 34-ha watershed that includes the main inlet to Cone Pond in the White Mountains of central New Hampshire. Cone Pond and its watershed are being used to study natural and human-caused acidification of forested and aquatic ecosystems (Buso and others 1985). Cone Pond watershed is underlain by a high-grade pelitic schist assigned to the Silurian Perry Mountain formation. The area was glaciated during the Pleistocene epoch. Soils are primarily Spodosols that have developed on Wisconsin-age glacial till that averaged <2 m deep. The watershed is forested with red spruce/balsam fir (78 percent) interspersed with patches of northern hardwoods (19 percent) and exposed bedrock (3 percent).

Methods

Predicting Lithologies

Our approach to predicting lithologic composition of soils at Cone Pond watershed is based on research by Goldthwaite and others (1951). They studied dispersal of nepheline syenite in glacial-till soils of New Hampshire and Vermont. Nepheline syenite is a distinctive and rare bedrock type in northeastern United States found only at Mount Ascutney, near Windsor, Vermont, and at Red Hill, near Moultonborough, New Hampshire. They found that fragments of nepheline syenite from these two discrete sources were dispersed in a 60° arc about the mean direction of glacial movement. Fragments of nepheline syenite were plentiful close to the source, but 32 km away, and still within the dispersal envelope, <0.1 percent of the rock fragments in the soil were nepheline syenite. This suggests that 32 km was about the maximum distance that rocks were transported by the glacier before being deposited in till, or disintegrating into sand-/silt-size fractions.

Based on these data for rock dispersal in till deposits, we determined a source area for the Cone Pond watershed by reversing such an envelope about the axis of glacial movement (Fig. 1). This area includes all bedrock types <32 km distant and within $\pm 30^\circ$ of the direction of glacial movement. The direction was based on glacial grooves and striations on exposed bedrock at the Cone Pond watershed. These markings were substantial in number and all were on an azimuth of about 151° , or close to the mean of regional values of 140 to 158° reported by Goldthwaite and others (1951). The area underlain by each lithology in the till source area was determined by plotting the envelope on the bedrock geologic map for New Hampshire (Fig. 1), then planimetrying.

Field Sampling

As a first approximation, we hypothesized that each lithology present in soils on Cone Pond watershed was proportional to its area in the source envelope (Fig. 1). To test this model, we excavated five, 20- x 20-cm soil pits chosen

to represent elevations, soil depths, and forest cover types on the Cone Pond watershed. All soil and rocks from the forest floor to the C horizon of each pit were removed and transported to the laboratory. After air drying and weighing, all rocks greater than 7 g (about 8 to 10 mm in diameter) were sawed in half to expose a cross section, and were then identified by lithologic unit. The minimum of 7 g was necessary because smaller fragments were rarely identifiable due to either extreme weathering or having an inadequate surface to show mineral and textural characteristics used to distinguish lithologic units.

Characterization of Weathering

To obtain estimates of the potential for rocks to contribute nutrients, weathering of rock fragments was characterized by measuring the thickness of the weathering rind on the cross section, and noting the extent of weathering features on a semi-quantitative basis. Iron staining and pitting were noted on a scale of 0 to 2, with 0 denoting not present, 2 denoting extensive staining or pitting throughout the specimen, and 1 denoting some staining or pitting in portions of the specimen. Other features rated as 0 (absent) or 1 (present) include the presence of fresh sulfides, alteration of feldspars to chalky material, and extensive overall weathering to the point where the sample was physically unstable under moderate finger pressure.

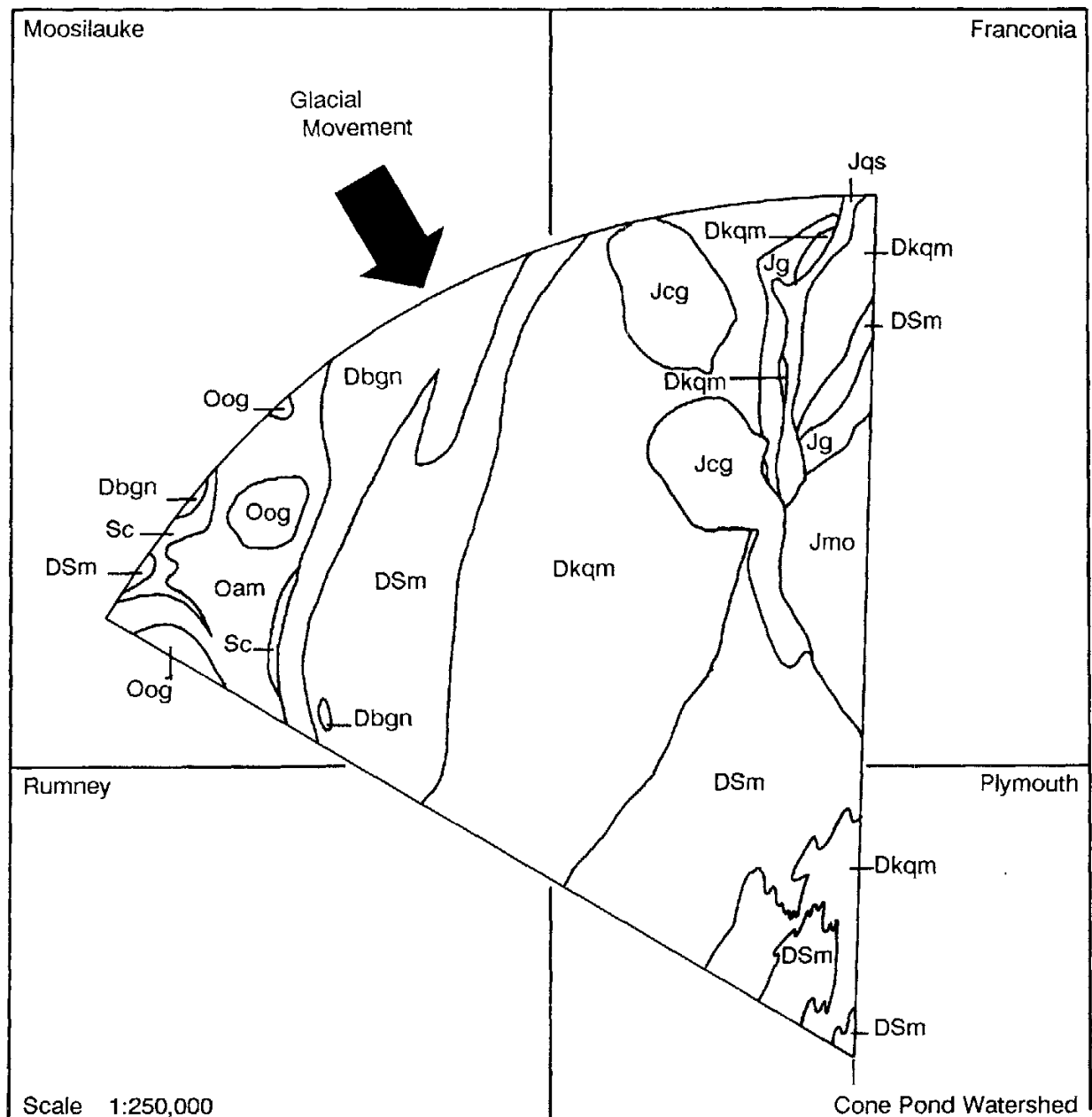
Results

Lithologic Composition

Field sampling from the five soil pits yielded a total of 302 rocks, each weighing >7 g. Rocks accounted for approximately 50 percent of the total weight of material from each sample pit, illustrating the rocky character of these forest soils. Characteristics of most rocks were distinctive enough to allow classification by lithologic unit. Only 1 percent of the fragments were completely unrecognizable, primarily due to extreme weathering alteration.

Table 1 shows the percentage of rock fragments by lithologic unit as predicted by their occurrence in the source envelope (Fig. 1) versus that observed by identifying field samples. Fragments of diabase dike rocks and pegmatite were found in small quantities (7 percent or less) but were not predicted by the model. Neither of these rocks were mapped in the source area due to the small nature of igneous bodies relative to existing mapping scales. The Oliverian Granite probably includes some Concord Granite (also called Binary Granite). These two rock types are difficult to distinguish when present in small fragments. Concord Granite was not mapped in the source envelope, but small plutons have been identified closer to Cone Pond watershed than have Oliverian plutons (C. Barton, U.S. Geological Survey, personal communication).

The formations of the Devonian-Silurian metasedimentary sequence were grouped since it was impossible to



Jqs	Garfield Quartz Syenite	Dbgn	Bethlehem Granite Gneiss
Jcg	Conway Granite	DSm	metasedimentary
Jmo	Mount Osceola Granite	Sc	Clough Formation
Jg	Lafayette Granite Porphyry	Oam	Ammonoosuc Volcanics
Dkqm	Kinsman Quartz Monzonite	Oog	Oliverian Granite

Figure 1.—Source envelope for predicting lithologic composition of soils on Cone Pond watershed. The envelope was drawn on the map of bedrock geology for New Hampshire revised in 1986. The main axis for the wedge is an azimuth of 151°, corresponding to the direction of glacial movement. Outlines of 15-minute U.S. Geological Survey quadrangles show location.

Table 1.—Rock fragments in soils of Cone Pond watershed

Age	Lithologic unit	Predicted occurrence by weight	Observed occurrence by weight
		<i>Percent</i>	
Jurassic	Diabase	0	1
	Garfield Quartz Syenite	1	1
	Conway Granite	8	4
	Mount Osceola Granite	4	1
	Lafayette Granite Porphyry	2	1
Devonian	Pegmatite	0	7
	Kinsman Quartz Monzonite	39	28
	Bethlehem Granite Gneiss	8	5
Devonian	Littleton Formation	29	43
Silurian	Madrid Formation		
	Smalls Falls Formation		
	Perry Mountain Formation		
	Rangeley Formation		
Silurian	Clough Quartzite	1	2
Ordovician	Ammonoosuc Volcanics	6	1
	Oliverian Granite	2	5
	Unknown	—	1
Total		100	100

Table 2.—Weathering characteristics of rock fragments

Characteristics	Weight	Mean mass of individual rocks	Number of specimens (n=302)
	<i>Percent of total</i>	<i>g</i>	<i>n</i>
Staining:			
None	40	64.8	71
Moderate	36	39.8	104
Intensive	24	22.2	127
Pitting:			
None	68	51.0	154
Moderate	22	40.7	62
Intensive	10	13.6	86
Chalky Feldspars	7	27.1	31
Sulfides	3	44.8	9
Extreme weathering	5	10.7	49
Total sample mean		38.2	

distinguish between these units in some fragments. All of these rocks have been mapped in the White Mountains as the Littleton Formation (Billings 1956). However, in the last 10 years, much of the Littleton has been reinterpreted as belonging to the various Silurian units first mapped in the adjacent region of western Maine by Moench (1971). Some of these units contain distinctive lithologies, such as calc-silicate granulite and sulfidic schist, which can be identified in small fragments. However, the majority of the rocks are quartz and mica schists which are only distinguishable by larger scale outcrop features or by stratigraphic position, or both.

For both the predicted and observed percentages, only Kinsman Quartz Monzonite and the Devonian-Silurian metasedimentary sequence contribute greater than 10 percent of the rocks found in the soil profile. The metasediments contributed 43 percent compared to 29 percent predicted whereas Kinsman contributed 28 percent compared to 39 percent predicted. The greater amount of observed metasediments and lesser amount of observed Kinsman may reflect the fact that bedrock underlying the watershed and areas immediately to the north is metasedimentary and was underpredicted due to its proximity (Fig. 1).

For the other lithologies, differences between predicted and observed weight may reflect variations in susceptibility to weathering, or distance from the source area to Cone Mountain. For example, Conway Granite and Bethlehem Granite Gneiss were overpredicted by the model. These are found only at distal parts of the source envelope (Fig. 1). Clough Quartzite, also found only at extreme distal areas of the source envelope, was slightly in excess of predicted amounts, possibly reflecting the resistance of quartzite to weathering and disintegration during transport.

The above results suggest that predictions could be improved by weighting lithologies by "up-glacier" distance from the Cone Pond watershed. We tested one simple weighting scheme by dividing the envelope into three sections based on equal distances along the 32-km radius, obtaining area of lithologies in each section, and then averaging to determine the overall prediction. The section of the envelope from 0 to 10.7 km had the smallest area but received the same weight as larger sections from 10.7 to 21.3 km and from 21.3 to 32 km. This approach improved the prediction for Devonian-Silurian metasedimentary units considerably, but still overestimated the proportion of Kinsman Quartz Monzonite (Table 1).

Descriptions of Weathering

Based on qualitative measures, weathering of small rock fragments is extensive (Table 2). Red to brown staining was evident on interiors of the majority of specimens sampled (Fig. 2), and 24 percent, by weight, were extensively stained throughout. The degree of staining was greater in smaller fragments.

A total of 148 specimens, or about half the sample,

exhibited moderate to extreme interior pitting (Table 2, Fig. 3). As with staining, smaller rocks exhibited a greater degree of pitting than larger rocks.

By weight, 3 percent of the sample showed fresh sulfides in interior portions (Table 2), indicating that some reserve of easily weathered minerals is still available. Thirty-one specimens, representing 7 percent by weight, had feldspar grains extremely altered (Table 2). These feldspars were quite soft (2 to 3 on the Mohs scale) and had a dull, chalky appearance, in contrast to an unweathered hardness of 5 to 6 on the Mohs scale and a vitreous appearance. The chemical consequences of this degree of alteration is unknown, but in granitic terranes, feldspar weathering may be the major source of base cations (Clayton 1986; Drever 1988).

Forty-nine specimens were so altered that they had lost their physical coherence. These were highly discolored and extensively pitted. The average size of these specimens was small (Table 2), indicating enhanced weathering of small particles.

Only 34 specimens exhibited the surficial rinds classically thought of as indicating rock weathering (Fig. 3). Rocks exhibiting rinds ranged from 7 to 527 g, and their rinds ranged up to 10 mm in thickness. Four rock types, Kinsman Quartz Monzonite, Bethlehem Granite Gneiss, Silurian metasedimentary, and Oliverian Granite, accounted for 93 percent of the rocks with rinds.

Discussion

A source envelope can easily be used to approximate lithologic composition of soils developed on glacial till. The information obtained can be used in conjunction with state bedrock maps to more fully understand geologic contributions to forest nutrient cycles.

Comparison of source areas between watersheds may help explain differences in weathering or base cation supply. For example, the annual net calcium loss (watershed inputs minus outputs) for Cone Pond watershed is $3 \text{ kg ha}^{-1} \text{ yr}^{-1}$ or 70 percent less than that for watersheds at the Hubbard Brook Experimental Forest located 12 km to the west. Since atmospheric loading and other factors are similar between the two sites, this difference in net loss has been hypothesized as being due to greater calcium contributions from rock weathering at Hubbard Brook.

Construction of a source envelope for Hubbard Brook shows that Ammonoosuc Volcanics account for 23 percent of the source area, compared to only 6 percent of the source area for the Cone Pond watershed. Ammonoosuc Volcanics is the only lithology in the region with a large amount of hornblende, a relatively unstable mineral in the weathering environment, and a prime source of calcium. Another major mineral in the Ammonoosuc Volcanics is plagioclase feldspar, also an important source of calcium. Three percent of the Hubbard Brook source area is underlain by the Fitch

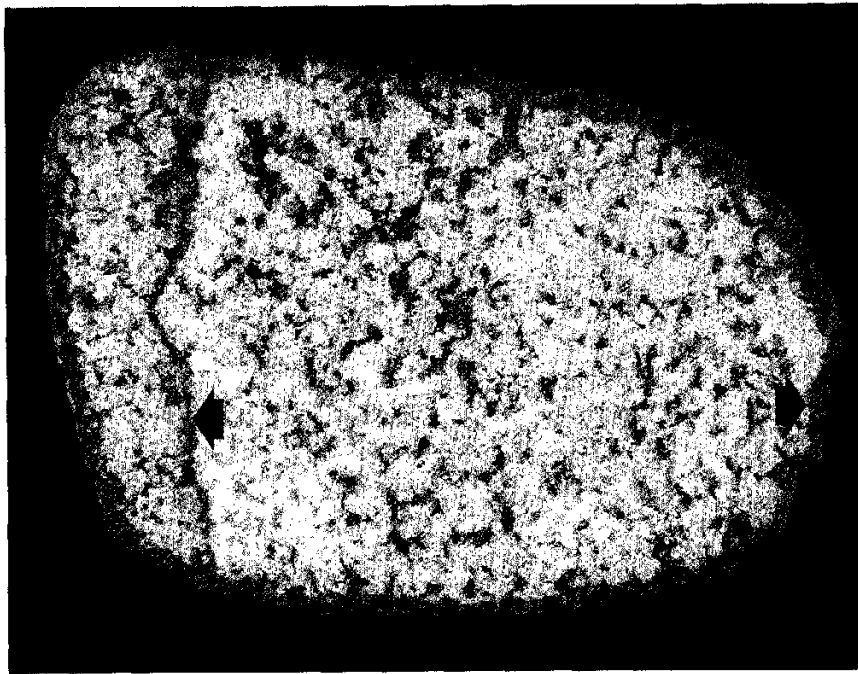


Figure 2.—Cross section of a granite fragment (347 g, 65 mm long) showing iron staining (arrows). The staining on the left side goes deeper for some unknown reason. Except for staining, the minerals in this fragment appear to be relatively fresh in that original luster and hardness are preserved.

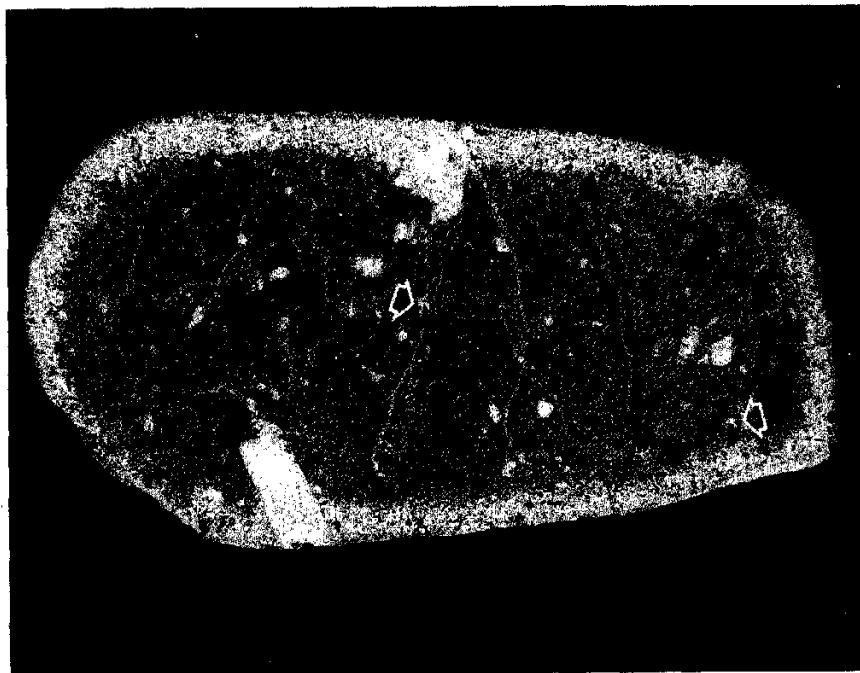


Figure 3.—Cross section of a diabase fragment (346 g, 67 mm long) showing weathering rind, interior dissolution pits (arrows), and weathered fractures.

formation, the only carbonate bearing lithology in the region. Carbonates are extremely reactive and disproportionately contribute base cations compared to silicates. None of these minerals are prevalent in other major lithologies found in till on the Cone Pond watershed. This scarcity of calcium sources may explain the lesser calcium outputs for Cone Pond watershed, and the low pH and acid neutralizing capacity of streamwater (Bailey and others 1987).

Predictions of lithologies in till soils may be of value when planning forest harvests. Soils developed on tills with rocks that are less resistant to weathering and that have high cation contents are apt to be more suitable for intensive harvests such as block clearcutting or whole-tree harvesting. Cations are likely to be in greater supply and losses due to harvest may be replenished more quickly by rock weathering. Lithologies like those found in till and soils on the Cone Pond watershed indicate a need for less intensive harvests and longer rotations.

Although the source envelope worked well for the Cone Pond watershed, there are limitations for other terranes. The method could not be expected to work where surficial materials have been deposited or extensively reworked by fluvial processes. Application also would be complicated where more than one episode of till deposition is preserved.

Current studies of forest nutrient cycling usually rely on analyses of soil particles <2 mm in diameter to obtain estimates of site nutrient capitals and readily available plant nutrients. However, rocks from the Cone Pond watershed showed extensive alteration (Figs. 2 and 3), suggesting that rock weathering could be providing significant contributions of nutrients beyond that indicated in the <2 mm fraction. The extensive staining found on the interior of the rocks represents dissolution, oxidation, and migration of iron in these rocks. The iron could be from soil water percolating through the rocks, or from weathering of iron-bearing minerals such as biotite commonly found in the rocks. In either situation, the observed staining indicates that the interiors of many rock fragments are vulnerable to weathering and are interacting with the forest nutrient cycle.

Interior pitting of rocks from our study site is caused by preferential dissolution of minerals that are more easily weathered than the overall rock mass. Sulfides and amphiboles are likely candidates for preferential dissolution in the rocks found in soil on the Cone Pond watershed. Dissolution pits were found in rocks as large as 209 g, which gives testimony to the potential of large, seemingly impermeable rocks to contribute to nutrient cycling.

When viewed under a dissecting microscope, interior pits, fractures, and exterior rinds appear sponge-like and highly porous. Thus, the active weathering surface is far greater than would be calculated for smooth rocks. The absence of classical weathering rinds on most rocks was a surprise. However, although rinds were lacking, most specimens had ragged and pitted surfaces. This may indicate that

weathering rinds are physically unstable, and that mechanical disintegration is concurrent with chemical alteration.

Literature Cited

- Bailey, S. W.; Hornbeck, J. W.; Martin, C. W.; Buso, D. C. 1987. **Watershed factors affecting stream acidification in the White Mountains of New Hampshire, USA.** Environmental Management. 11: 53-60.
- Billings, M. P. 1956. **The geology of New Hampshire. II. Bedrock geology.** Concord, NH: New Hampshire Department of Resources and Economic Development. 200 p.
- Buso, D. C.; Bailey, S. W.; Baird, F.; Hornbeck, J. W.; Martin, C. W. 1985. **Watershed interactions affecting pond acidification.** Durham, NH: Water Resources Research Center, University of New Hampshire; Res. Rep. No. 62. 61 p.
- Clayton, J. L. 1986. **An estimate of plagioclase weathering rate in the Idaho batholith based upon geochemical transport rates.** In: Colman, S. M.; Dethier, D. P., eds. Rates of chemical weathering of rocks and minerals. Orlando, FL: Academic Press: 453-466.
- Drever, J. I. 1988. **The geochemistry of natural waters.** Englewood Cliffs, NJ: Prentice Hall. 437 p.
- Federer, C.A.; Hornbeck, J. W.; Tritton, L. M.; Martin, C. W.; Pierce, R. S.; Smith, C. T. 1989. **Long-term depletion of calcium and other nutrients in eastern US forests.** Environmental Management. 13: 593-601.
- Goldthwaite, J. W.; Goldthwaite, L.; Goldthwaite, R. P. 1951. **The geology of New Hampshire. Part I. Surficial geology.** Concord, NH: New Hampshire Department of Resources and Economic Development. 83 p.
- Likens, G. E.; Bormann, F. H.; Pierce, R. S.; Eaton, J. S.; Johnson, N. M. 1977. **Biogeochemistry of a forested ecosystem.** New York: Springer-Verlag. 146 p.
- Moench, R. H. 1971. **Geologic map of the Rangeley and Phillips quadrangles, Franklin and Oxford Counties, Maine.** Washington, DC: U.S. Geological Survey; Misc. Geol. Invest. Map I-605.
- Paces, T. 1986. **Weathering rates of gneiss and depletion of exchangeable cations in soils under environmental acidification.** Journal of Geological Sciences. 143: 673-677.
- Shortle, W. C.; Smith, K. T. 1988. **Aluminum-induced calcium deficiency syndrome in declining red spruce.** Science. 240: 1017-1018.

Bailey, Scott W.; Hornbeck, James W. 1992. **Lithologic composition and rock weathering potential of forested, glacial-till soils.** Res. Pap. NE-662. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Describes methods for predicting lithologies present in soils developed on glacial till, and the potential weathering contributions from rock particles >2 mm in diameter. The methods are not quantitative in terms of providing weathering rates, but provide information that can further the understanding of forest nutrient cycles, and possibly assist with decisions about forest harvesting.

Keywords: weathering rate, soil formation, nutrient cycling

Headquarters of the Northeastern Forest Experiment Station is in Radnor, Pennsylvania. Field laboratories are maintained at:

Amherst, Massachusetts, in cooperation with the University of Massachusetts

Burlington, Vermont, in cooperation with the University of Vermont

Delaware, Ohio

Durham, New Hampshire, in cooperation with the University of New Hampshire

Hamden, Connecticut, in cooperation with Yale University

Morgantown, West Virginia, in cooperation with West Virginia University

Orono, Maine, in cooperation with the University of Maine

Parsons, West Virginia

Princeton, West Virginia

Syracuse, New York, in cooperation with the State University of New York, College of Environmental Sciences and Forestry at Syracuse University

University Park, Pennsylvania, in cooperation with The Pennsylvania State University

Warren, Pennsylvania

Persons of any race, color, national origin, sex, age, religion, or with any handicapping condition are welcome to use and enjoy all facilities, programs, and services of the USDA. Discrimination in any form is strictly against agency policy, and should be reported to the Secretary of Agriculture, Washington, DC 20250.

"Caring for the Land and Serving People Through Research"