tribute to external gamma radiation and its possible genetic effects. It is clear that estimates of future contamination from high-yield detonations at north temperate latitudes must be revised upward from estimates based on 5- to 10-year periods of stratospheric storage (32).

References and Notes

1. The Sunshine Project was supported by the Division of Biology and Medicine of the U.S. Atomic Energy Commission, under contract AT (11-1)-281. It was initiated by W. F. Libby, carried out under his direction from July 1953 to October 1954, and continued under the direction of E. A. Martell from October 1954 to its termination in August 1956.
2. W. F. Libby, *Proc. Natl. Acad. Sci. U.S.* 42, 365 (1956).
3. ———, *ibid.* 42, 945 (1956).
4. ———, *ibid.* 43, 758 (1957).
5. ———, "Radioactive fallout," a paper presented before the Swiss Academy of Medical Sciences Symposium on Radioactive Fallout, Lausanne, 27 March 1958.
6. E. A. Martell, *U.S. Atomic Energy Comm. Rept. No. AECU-3262* (May 1956).
7. ———, *U.S. Atomic Energy Comm. Rept. No. AECD-3763* (Jan. 1957).
8. ———, *U.S. Atomic Energy Comm. Rept. No. AECU-3297* (Jan. 1957).
9. *Science* 124, 105 (1956); "The Biological Effects of Atomic Radiation, Summary Reports," *Natl. Acad. Sci.–Natl. Research Council Publ.* (1956).
10. "The nature of radioactive fallout and its effects on man," *Hearings before the Special Subcommittee on Radiation of the Joint Committee on Atomic Energy, May 27–29, June 3–7, 1957, pts. 1 and 2* (U.S. Government Printing Office, Washington, D.C., 1957).
11. N. G. Stewart, R. G. D. Osmond, R. N. Crooks, E. M. Fisher, "The world-wide deposition of long-lived fission products from nuclear test explosions," *Atomic Energy Research Establ. (G. Brit.) Publ. No.* AERE HP/R 2354 (Oct. 1957).
12. D. R. Wiles and R. H. Tomlinson, *Can. J. Phys.* 33, 133 (1955).
13. L. E. Glendenin and E. P. Steinberg, *United Nations Conf. on Peaceful Uses of Atomic Energy, 1st Conf., Paper No. 8/P/614* (1955).
14. G. W. Reed, *Phys. Rev.* 98, 1327 (1955). Reed's result for Sr^{90} corresponds to a 5.6-percent yield for a 28-year half-life. (See also footnote 15 of Reed's paper.)
15. C. E. Adams, N. H. Farlow, W. R. Schell, "The compositions, structures, and origins of radioactive fallout particles," *U.S. Naval Radiological Defense Lab. Publ. No. USNRDL-TR-209* (Feb. 1958).
16. N. G. Stewart, R. N. Crooks, E. M. Fisher, *Atomic Energy Research Establ. (G. Brit.) Publ. No. AERE HP/R 1701* (June 1955).
17. L. Machta, "Discussion of meteorological factors and fallout distribution," paper presented before the annual meeting of the American Association for the Advancement of Science (Dec. 1957).
18. A. W. Brewer, *Quart. J. Roy. Meteorol. Soc.* 75, 351 (1949).
19. G. M. B. Dobson, *Proc. Roy. Soc. (London)* 236A, 187 (1956).
20. I. H. Blifford, Jr., H. Friedman, L. B. Lockhart, Jr., R. A. Baus, *J. Atmospheric and Terrest. Phys.* 9, 1 (1956).
21. I. H. Blifford, Jr., and H. B. Rosenstock, *Science* 123, 619 (1956).
22. "Environmental contamination from weapons tests," *U.S. Atomic Energy Comm. Health and Safety Lab. Publ. No. HASL-42* (Oct. 1958).
23. Personal communication from L. T. Alexander, Soil Survey Laboratory, U.S. Department of Agriculture, Beltsville, Md.
24. F. J. Bryant, A. C. Chamberlain, A. Morgan, G. S. Spicer, *J. Nuclear Energy* 6, 22 (1957).
25. W. R. Collins and N. A. Hallden, *U.S. Atomic Energy Comm. Health and Safety Lab. Rept. No. NYO-4889* (Apr. 1957).
26. P. J. Drevinsky, C. E. Junge, I. H. Blifford, Jr., M. I. Kalkstein, E. A. Martell, Air Force Cambridge Research Center publ., in press.
27. F. Begemann, "Tritium Assays of Natural Waters Measured in 1956–1957," report on Air Force contract No. AF 18 (600)-564 (31 Dec. 1957); *Air Force Office of Strategic Research Publ. No. TR58-41; Armed Services Tech. Inform. Agency Publ. No. 154131.*
28. R. G. Osmond, A. G. Pratchett, J. B. Warricker, *Atomic Energy Research Establ. (G. Brit.) Publ. No. AERE C/R 2165* (1957).
29. *Effects of Atomic Weapons* (U.S. Government Printing Office, Washington, D.C., 1957).
30. F. W. P. Götz and F. Volz, *Z. Naturforsch.* 6a, 634 (1951).
31. H. Wexler, *Bull. Am. Meteorol. Soc.* 32, 48 (1951).

32. I am indebted to Dr. W. F. Libby, Dr. L. T. Alexander, Dr. R. A. Craig, Dr. C. E. Junge, and Mr. I. H. Blifford, Jr., for numerous helpful discussions and suggestions. I wish to thank Dr. Henri Bader of the Snow, Ice and Permafrost Research Establishment (Wilmette, Illinois), Mr. Paul Humphrey of the U.S. Weather Bureau, and members of the U.S. International Geophysical Year organization for their generous assistance in obtaining the snow samples from Antarctica and Greenland.

Recent Saprolite

Thick saprolite has formed in northern New Jersey since the last Pleistocene glacial stage.

James P. Minard

Thick saprolite is present in glaciated terrane of northern New Jersey under field conditions suggesting formation within a comparatively short time interval. The saprolite has developed on a low spur lying along the east side of a glaciated valley, normal to the direction of former ice movement. It is quite probable that the saprolite has weathered from consolidated rock since the latest (Wisconsin) glacial period.

A gneissic saprolite, the maximum age of which is possibly determinable, is present in northern New Jersey, 5 miles north of the southern static limit of Wisconsin glaciation. The saprolite is exposed in a pit along the east side of route 206, east of Cranberry Lake, Sussex County. The saprolite is along the west side and near the base of a north-trending bedrock ridge; it forms a benchlike spur, the upper surface of which is 50 to 60 feet above the swampy terrain west of the highway.

The rock from which the saprolite formed is shown on the geologic map as Pochuck gneiss of Precambrian age (Fig. 1). The rock is an amphibolite gneiss containing much hornblende, considerable oligoclase and diopside, and some quartz, magnetite, and microperthite.

Outcrop Description

A thickness of nearly 15 feet of saprolite is exposed in a pit approximately 200 feet wide and 300 feet long. The saprolite is easily excavated and crumbles readily, under hand pressure, into a sticky, clayey, gritty mass. At least 12 feet of saprolite underlies the pit bottom, giving a minimal thickness of 25 feet. Because of the gentle slope and absence of bedrock downhill from the pit, the total thickness of saprolite may be as much as 40 feet. Overlying the saprolite in the pit is several feet of well-weathered glacial till. Except for a shallow A horizon of the soil profile, the till and the upper few inches of the saprolite apparently comprise the 2- to 3-foot-thick B horizon of the soil profile, and the rest of the saprolite forms the deep C horizon. By comparison, saprolite formed from unglaciated gneiss 3 miles south of Chester (see Fig. 2) is nearly 60 feet thick and has a substantial A horizon and a thick (5 to 6 feet) B horizon.

Remarkably continuous light and dark gneissic layering can be seen in the exposure (see Figs. 3–5). These layers are one-eighth to 1 inch thick and are many feet long. The layering dips approximately 15° south, except in the west

The author is on the staff of the photogeology section of the Alaskan geology branch, U.S. Geological Survey, Washington, D.C.

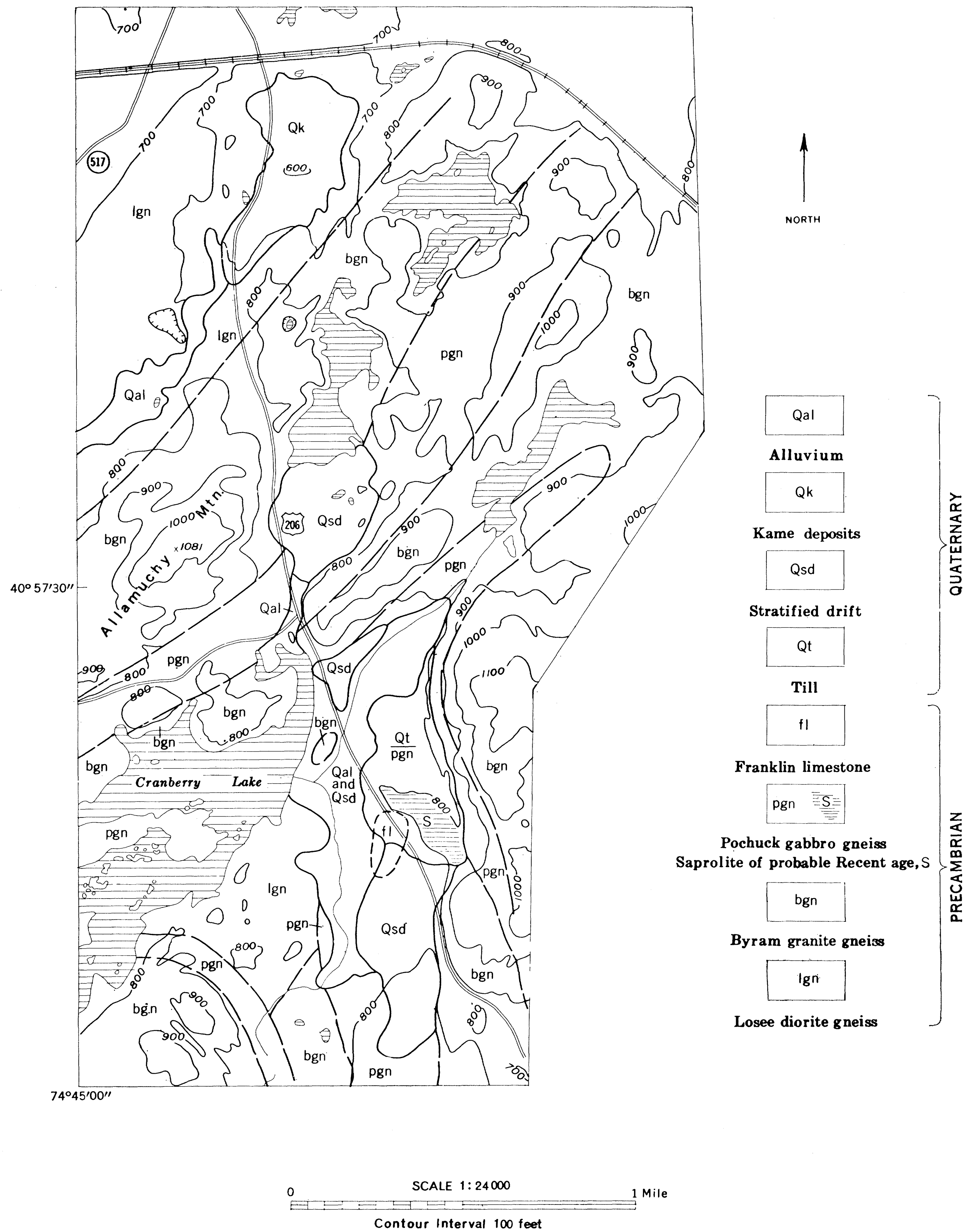

Fig. 1. Generalized geologic map of saprolite area. [W. S. Bayley, R. D. Salisbury, H. B. Kummel, "Geologic atlas of the United States, Raritan folio," *U.S. Geol. Survey Publ.* (Government Printing Office, Washington, D.C., 1914)].

part of the pit, where, near the contact with the overlying glacial till, it becomes nearly horizontal. This may be the result of soil creep down the slope. Except for this slight bending, the gneissic layering is neither deformed nor distorted at or below the contact with the glacial till.

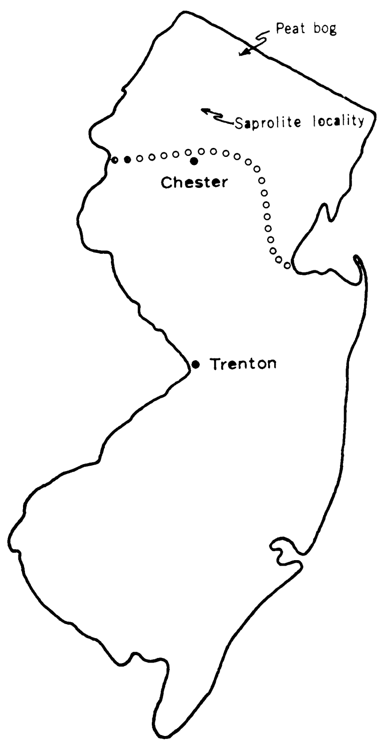

Fig. 2. Map of New Jersey, showing the saprolite location and the postglacial peat bog from which samples were taken for carbon-14 analysis. The line of circles represents the terminal moraine of the Wisconsin stage of continental glaciation.

Evidence for Dating

The significance of this exposure of saprolite lies in its presence several miles north of the terminal moraine of the Wisconsin stage of continental glaciation. Bare, glacier-scoured bedrock hills and ridges typify the area. Almost all unconsolidated material in the area is glacial till or drift. Only small patches of residual soil are present, and these are extremely thin.

Here, beneath several feet of glacial till, is at least 25 feet of well-weathered (*in situ*), easily excavated rock material that forms an obstructing spur projecting into a glaciated valley that trends essentially parallel with the direction of former ice movement. It seems improbable that the rotten rock could have survived the glacial erosion had it been, at that time, in its present physical state, or that the gneissic layering would be without distortion or deformation at the sharp contact with the glacial till. It may be postulated that the saprolite was formed prior to glaciation and escaped removal because it was frozen. However, some indication of its frozen state, such as congeliturbate structure, would be expected. The silty, clayey texture of the saprolite would have made it highly susceptible to freeze-thaw processes. If, on the contrary, it is assumed that the rock from which the saprolite developed was essentially unweathered resistant rock during the glacial period, it must have undergone nearly complete weathering to its present crumbly state since glacial time. This period of weathering may be as much as 18,000 to 20,000 years, if the terminal moraine a few miles to the south correlates with the climax of the Wisconsin stage of continental glaciation, or as little as 12,000 to 13,000 years, if the moraine correlates with the latest pulse of the Wisconsin glaciation (*1*).

A carbon-14 date was established (*2*) from peat obtained in northeastern Sussex County. The sample was submitted by Meredith E. Johnson (*3*) and was taken from a bog in which a nearly complete mastodon skeleton was found buried under 9 feet of peat. The peat and mastodon remains rested on glacial till. The depth of the peat increased to approximately 20 feet just west of the mastodon remains. The location of the bog, shown in Fig. 2, is three-fourths of a mile west of Highland Lake. The age of the peat was determined to be 10,890 ± 200 years.

A clearly defined recessional moraine is present east-west across Sussex County, 10 miles south of the bog. The recessional moraine probably correlates with the latest pulse of the Wisconsin stage and is older than the bog by as much as several thousand years (time for a sufficient static stage to allow formation of the prominent moraine, withdrawal for 10 miles, and formation of 5 to 10 feet of peat). The saprolite lies 10 miles south of the recessional moraine, and the terminal moraine which probably correlates with the climax of the Wisconsin stage (18,000 to 20,000 years ago?), is 5 miles south of the saprolite. The saprolite dates somewhere between the 14,000- to 15,000-year-old pulse and the 18,000- to 20,000-year-old climax of the Wisconsin glaciation.

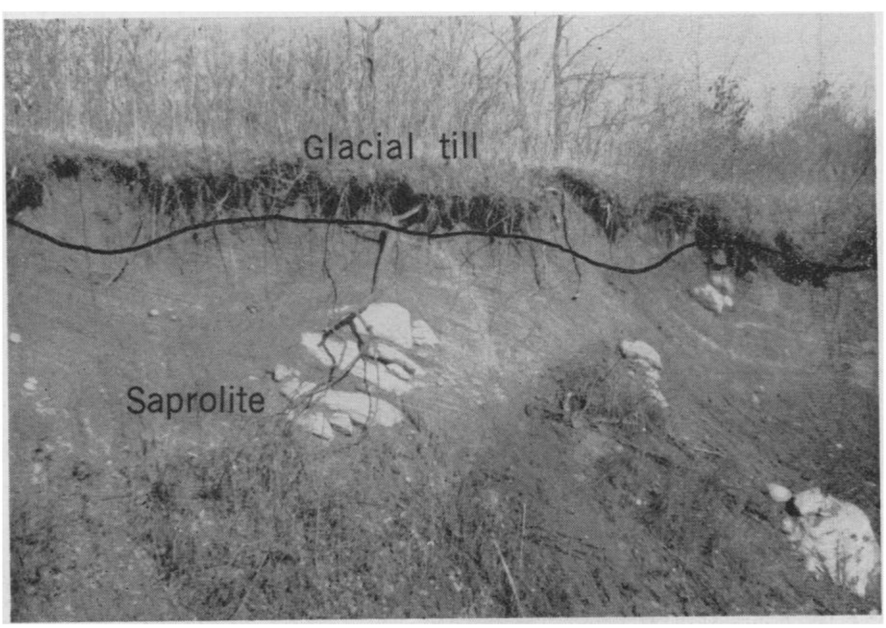

Fig. 3. View of the north wall of the pit, showing layering in the saprolite and in the included consolidated rock.

Rapid Weathering

Several favorable conditions or factors may have contributed to the rapid, deep weathering of the Pochuck gabbro gneiss. MacClintock (*4*) made a study of weathered gneiss pebbles and cobbles in the Jerseyan drift (partly correlative with the Kansan stage and recognized only south of the Wisconsin drift). Many of the gneiss pebbles and cobbles in the Jerseyan drift can be crumbled easily by hand pressure (I have observed similar cobbles in the Wisconsin drift at several localities in Sussex County). MacClintock attributed the advanced weathering to several conditions and factors other than the chemical nature of the rock. They are (i) a humid climate and considerable precipitation; (ii) a location well above the permanent ground-water

Fig. 4. Close-up of the saprolite and the consolidated rock. The gneissic layering is continuous from the saprolite through the consolidated rock.

table; (iii) a certain amount of clayey or silty fractions in the drift. The first provided a copious supply of water; the second assured an exchange of percolating water, so that when any unit of water had dissolved rock constituents to its capacity, more fresh water could take its place; and the third retarded percolation somewhat, so that nearly maximum leaching was accomplished by any unit of water. MacClintock found that the highest percentage of completely weathered gneissic pebbles and cobbles was in the silty and clayey layers of the drift.

These conditions existed in the saprolite locality. The saprolite spur has received a considerable amount of precipitation; it is well above the ground-water table; and, because of a tight joint system in the initial phases of weathering and the presence of residual and illuviated clayey constituents in later phases, ground-water percolation has been retarded. Furthermore, because the saprolite spur is near the base of a long slope, it receives a considerable amount of water for some time after each precipitation.

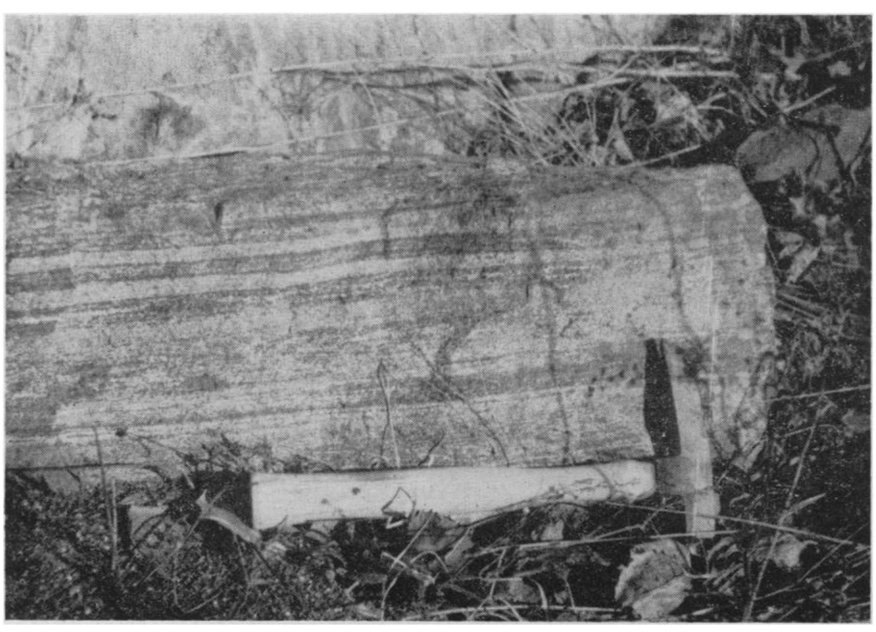

Fig. 5. Close-up of consolidated rock from the saprolite. The layering is uniform and continuous.

Supporting evidence for rapid, deep weathering is reported in Hunt and Sokoloff's paper (*5*). "Deep soils representing the residual effect of rock weathering are commonly attributed to considerable absolute age, but the age is probably one of the least important of all the factors that must have controlled the development of so deep and mature a profile as characterizes this soil. . . . It is even possible that the paleosol (approximately 20+ feet) actually required no longer time to develop than has been required by the shallow Wisconsin (approximately 2 feet) and younger soils in this region. Given favorable moisture and temperature conditions and appropriate animal and vegetable life to accelerate biochemical activity, it is not at all difficult to visualize rather rapid rock decomposition and deep soil development."

Conclusion

The presence of a relatively thick occurrence of soft, crumbly gneissic saprolite in a predominantly glacier-scoured bedrock terrane offers a possible means of determining the rate of weathering of the parent rock. Analysis of the supporting evidence indicates that the rock from which the saprolite formed must have been essentially unweathered when overridden by the ice. The supporting evidence includes (i) the position of the saprolite on a spur projecting into a glaciated valley and subject to severe glacial scouring; (ii) the lack of distortion or deformation of the gneissic layering at the contact with the overlying glacial till; and (iii) the absence of any comparable residual soil, with similar boundary conditions, elsewhere in the glacier-scoured bedrock terrane of this vicinity.

On the basis of this evidence, I believe that the saprolite formed as a result of weathering of the Pochuck gabbro gneiss of Precambrian age since the last withdrawal of the ice, somewhere between 14,000 to 15,000 and 18,000 to 20,000 years ago (*6*).

References and Notes

1. R. F. Flint and M. Rubin, *Science* 121, 649 (1955).
2. Sample No. L-231 in W. S. Broecker and J. L. Kulp, *ibid.* 126, 1329 (1957).
3. Dr. Johnson is state geologist of New Jersey.
4. P. MacClintock, *Bull. Geol. Soc. Am.* 51, 103 (1951).
5. C. B. Hunt and V. P. Sokoloff, "Pre-Wisconsin soil in the Rocky Mountain region, a progress report," *U.S. Geol. Survey Profess. Paper No. 22* (1949), pp. 117–118.
6. Publication of this article was authorized by the director of the U.S. Geological Survey.