seedlings with soil structure essentially intact. The sample site is in a mixed hardwood stand in southern Indiana. The soil is classed as Wellston silt loam and the *p*H is about 6.

Autoclaving and gassing with methyl bromide were used for sterilization, and both methods proved satisfactory. For convenience, gassing was used in most of the tests. Both small plugs of natural forest soil and macerated roots of forest-grown yellow poplar seedlings were used to supply inoculum for sterilized containers. The yellow poplar root inoculum was prepared by washing roots thoroughly in distilled water, washing them in a 0.5-percent water solution of sodium hypochlorite, and re-washing in distilled water. Then the roots were cut and macerated in a mortar. This procedure was followed to decontaminate the root surfaces as much as possible. About 2 to 3 g fresh weight of macerated roots were added to each container. Sections of roots used for inoculum were examined and found to be infected with endotrophic mycorrhizal fungi.

The macerated roots used in this study are not a pure inoculum. There is the possibility that other microorganisms remain as contaminants on the root surfaces even after washing in sodium hypochlorite. Unfortunately, techniques for producing pure inoculum of endotrophic fungi are not yet available. Other known work with the endotrophs has had the same general deficiency as the present study. For example, in a German study with corn (*4*) the inoculum used was corn roots.

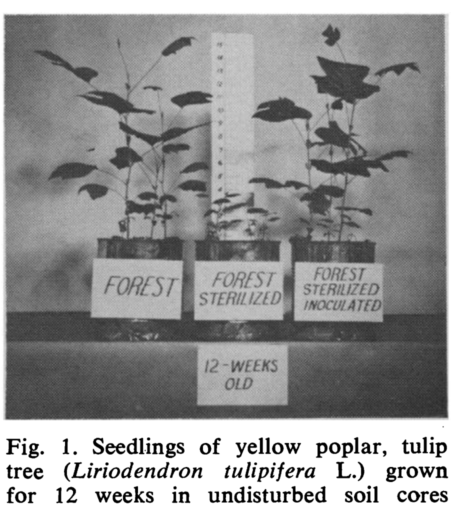

Fig. 1. Seedlings of yellow poplar, tulip tree (*Liriodendron tulipifera* L.) grown for 12 weeks in undisturbed soil cores from a forest site demonstrated that endotrophic mycorrhizal fungi influence growth. (Left) Seedlings grown in unsterilized soil were infected. (Center) Seedlings grown in sterilized soil were nonmycorrhizal and nonvigorous. (Right) Seedlings in sterilized soil inoculated with yellow poplar roots were mycorrhizal.

Yellow poplar seeds were germinated in trays and planted in the containers of undisturbed soil. The seedlings were grown on a 14-hour day under artificial light for 12 weeks. Distilled water was used for watering. Three replications (containers) of each treatment were ample to demonstrate statistical differences in seedling size in each of four separate studies. Seedlings were recovered nearly intact from the containers by soaking and washing. Examination of the root systems for mycorrhizal fungi was made by Hacskaylo (*5*).

Growth differences among the various treatments were outstanding (Fig. 1). In the most recent study total fresh weight of roots and tops averaged 1.6 g per seedling in sterilized containers. In contrast, seedlings from unsterilized containers and sterilized containers inoculated with macerated yellow-poplar roots averaged 7.7 and 9.0 g, respectively. Microscopic sections of the root systems revealed that the seedlings from sterilized containers were nonmycorrhizal, while seedlings from unsterilized and sterilized-inoculated containers were mycorrhizal.

It is interesting that the influence of the fungus was not effective immediately. At 7 weeks there was no height difference between seedlings in sterilized and sterilized-inoculated containers. Evidently the organism or the host plant must reach a certain stage of development before the mycorrhizal infection becomes effective.

Soil structure greatly influenced seedling growth. Moist soil from the sample site was sieved through a ⅜-inch-mesh screen and potted. Coarse litter and roots were discarded from the sieved soil, otherwise the sieved and undisturbed soil samples were identical except for porosity. After 12 weeks, seedlings in the sieved soil weighed only a sixth as much as seedlings grown in undisturbed forest soil. Seedlings in sieved soil were only 3.1 inches tall compared with 10.3 inches for seedlings in undisturbed soil. Sieving did not exclude mycorrhizal development but the infection was slight. So the successful demonstration of the influence of mycorrhizae on yellow-poplar growth was due primarily to the use of undisturbed natural soil.

The influence of endotrophic mycorrhizae on the growth of yellow-poplar was clearly demonstrated. Nutritional studies of other plants normally infected by endotrophs should be designed to evaluate the relations between the host plant and associated fungi. The use of containers with the soil structure essentially undisturbed provides optimum growing conditions and an opportunity for maximum differences among experimental treatments.

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References and Notes

1. B. Mosse, *Nature* **179**, 922 (1957).
2. G. T. S. Baylis, *New Phytologist* **58**, 274 (1959).
3. For details on sampling technique, see: F. Bryan Clark, *1960 Proc. Indiana Acad. Sci.* **70**, 234 (1961).
4. A. G. Winter and K. A. Meloh, *Naturwissenschaften* **45**, 319 (1958).
5. Dr. Edward Hacskaylo, plant physiologist, U.S. Department of Agriculture, Forest Service, Beltsville, Md.

8 April 1963

Tracks of Charged Particles in High Polymers

Abstract. *Heavily ionizing particles create trails of damage as they move through materials. In both addition and condensation polymers these trails can be selectively dissolved so that the sites and the directions taken by the moving particles are revealed. These materials thus serve as simple detectors of heavily charged particles.*

In many crystalline solids irradiation by heavily ionizing particles such as fission fragments produces trails of damage (*1*). This may be revealed by preferential chemical attack, that identifies the sites of damage by etch pits (*2*). Long, narrow etch channels may be produced (*3*) which identify the direction of the damage trail as well as the location of the damage. These phenomena occur also in inorganic glasses (*4*) and hence are not restricted to crystalline solids. Here we describe the observation of charged particle tracks in several organic high polymers.

We have demonstrated the particle-etching effect by bombardment with several high-energy, massive particles—including 400 Mev argon ions (*5*). The most convenient and rapid procedure, however, is irradiation of a selected area with fragments from the spon-

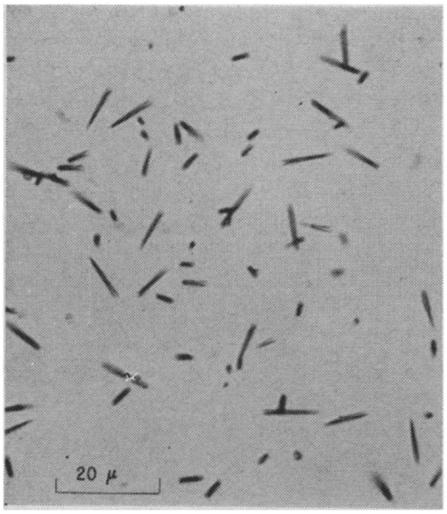

Fig. 1. Fission fragment tracks in Lexan.

taneous fission of Cf^{252}. The sample is then immersed in a suitable chemical reagent, rinsed, dried, and examined in an optical microscope. We find deep pits or tracks on the irradiated portion, but not elsewhere; and the number of pits is equal to the number of incident fission fragments. Alpha particles emitted by the Cf^{252} did not lead to observable pits.

We have produced pits indicating fission fragment tracks in condensation polymers—bisphenolacetone carbonate (Lexan), polyethylene glycol terephthalate (Mylar), cellulose nitrate, cellulose acetate—and in an addition polymer—polymethyl methacrylate (Plexiglas). Successful etching solutions were a mixture of aqua regia and hydrofluoric acid 6:1 for Plexiglas, NaOH in water (specific gravity 1.3) for Lexan resin, and KOH in water (specific gravity 1.4) for the other polymers mentioned.

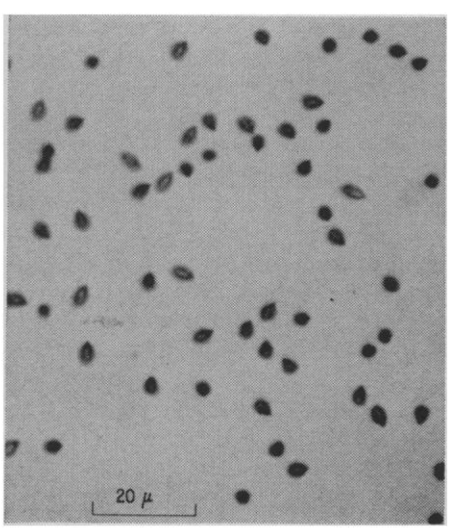

Fig. 2. Fission fragment tracks in cellulose nitrate. Round pits are from fragments crossing normal to the surface; pointed cones correspond to fragments which entered at acute angles.

Generally, tracks lengthen and widen in linear fashion with increased time of solution until some maximum length is reached. Tracks therefore have a conical shape, with the cone angle θ depending on the ratio R of the chemical-attack rate along the damaged material of the track to the general rate of attack of the undamaged material. For large values of R, $\theta (= 2 \csc^{-1} R)$ is small and the pits approach channels in shape and hence accurately define the direction taken by fission fragments.

Figure 1 shows a random array of tracks from a sample of Lexan polycarbonate which was placed close to the source of fission fragments. In Fig. 2 are pits produced in cellulose nitrate under conditions where θ is not small, and therefore the conical form of the pits is evident. Tracks in Lexan have a maximum length of about 20 microns, which is about the estimated range of fission fragments for this material.

Annealed cellulose acetate shows pits of angle intermediate between that of Lexan resin and cellulose nitrate. Cellulose acetate in its usual form gave pits which were ragged and ill-defined. Since this behavior was eliminated by annealing before irradiation, we conclude that internal stresses from processing or molecular alignment or both were responsible for the original behavior. If Lexan resin is annealed for 20 minutes after irradiation, tracks still may be detected above 185°C.

Plastic such as Lexan resin constitutes a simple and useful new type of solid-state detector for observing nuclear events of massive particles. An appreciable amount of a heavy element can be dissolved in the plastic as an organometallic compound (for example triphenylbismuthine). Since alpha particles do not lead to detectable tracks, irradiations may be performed with light particles without obscuring the tracks of interest, those that result from the massive particle interactions (such as fission) produced by irradiation. Plastics have the desirable property generally of being composed of elements of low atomic mass, so that scattering of heavy particles is very much smaller than in nuclear emulsions (*5; 6*).

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References and Notes

1. E. C. H. Silk and R. S. Barnes, *Phil. Mag.* **4**, 970 (1959).
2. D. A. Young, *Nature* **182**, 375 (1958).
3. P. B. Price and R. M. Walker, *J. Appl. Phys.* **33**, 3407 (1962); ———, *Phys. Rev. Letters* **8**, 217 (1962); **3**, 113 (1962); R. L. Fleischer, P. B. Price, R. M. Walker, *Rev. Sci. Instr.*, in press.
4. R. L. Fleischer and P. B. Price, in preparation.
5. R. L. Fleischer, E. L. Hubbard, P. B. Price, R. M. Walker, in preparation.
6. We thank A. Ghiorso for making possible the Cf^{252} irradiations and R. P. Kambour and R. E. Robertson for helpful discussions. Supported in part by the Air Force Cambridge Research Center.

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Microfossils in Wisconsinan Loess and Till from Western Illinois and Eastern Iowa

Abstract. *Wisconsinan loess from Illinois and Iowa contains a varied assemblage of microfossils including radiolaria, foraminifera, sponge spicules, and opal phytoliths. The foraminifera and radiolaria are derived from Cretaceous rocks occurring on the northern Great Plains. The sponge spicules are from fresh-water sponges living during the epoch of loess deposition. The phytoliths were produced by vegetation growing during deposition. These microfossils are valuable in determining loess and till provenance and in paleoecological reconstruction.*

Loess deposits of Illinois are particularly suited to study and correlation because of their great depth and extensive distribution. The extent and nature of these deposits have been described and correlated by Smith (*1*), Leighton and Willman (*2*), and more recently Frye, Glass, and Willman (*3*). These studies have indicated that the source of Illinois loess may be quite distant and that loess distribution and thickness is closely dependent on drainage-system distribution.

In the course of investigation of Illinois loess, microfossil assemblages composed of radiolaria, foraminifera, sponge spicules, and opal phytoliths have been discovered. These fossils were found in the isolate of less than 2.30 specific gravity, which was obtained by centrifugation of 2.5 to 3.0 g of sample with a nitrobenzene-bromoform mixture. The calcareous foraminifera are buoyant because they are air filled. The yield of fossils from a 3-g sample is often quite small, and it is necessary to use care in removing the fossils from the tube; this is best ac-