growth rates. At the growth rates indicated, the largest nodules observed would have initiated growth approximately 1600 years ago. This could indicate a physical limit on concretion size at approximately 16 cm or a physicochemical change in lake conditions 1600 years ago. A detailed study of the ferromanganese bands in freshwater nodules could provide a new method for the interpretation of past hydrochemical conditions in lakes.

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Particle Track Enhancement in Cellulose Nitrate by Application of an Electric Field

Abstract. *The number and length of etchable tracks, created by alpha particles in a cellulose nitrate sheet, are significantly enhanced by the application of an electric field across the cellulose nitrate.*

When a highly ionizing particle traverses a dielectric medium, it disrupts atomic and molecular structure along its path. Subsequent etching preferentially attacks this region of damage, thus causing the resulting track to become visible (*1*). We have observed enhancement of the damage created by low-energy alpha particles through the application of an electric field across the dielectric cellulose nitrate during the passage of the particle.

Two principal mechanisms, compatible with available data, have been suggested to explain the processes by which the track damage is created. Fleischer *et al.* (*2, 3*) have proposed a mechanism called the "ion explosion spike." According to this model, a highly ionizing particle leaves behind a small cone or cylinder of positively charged ions. If the ion density is sufficiently high, mutual Coulomb repulsion will eject the ions into the surrounding lattice. This leaves a region containing many dislocated atoms that is chemically reactive. However, this mechanism is not sufficient to explain etchable track formation by alpha particles in polymers. In a polymeric material such as cellulose nitrate, less energy is required to break the chemical bonds than to ionize the atoms. Hence it has been suggested (*2*) that the breaking and rearranging of the chemical bonds in polymeric materials contribute to the damage mechanism.

A second mechanism, proposed by Benton (*4*), suggests that delta-ray electrons, created by the passage of the ionizing particle, are responsible for the necessary damage. Molecular fragments, created by the delta rays, are then more soluble in the etchant than the unfragmented molecules of the dielectric.

The nature of the mechanism for energy loss in matter is such that many atoms, while receiving some energy from the passage of the ionizing particle, decay rapidly to the ground state with no permanent change in the material. If the excited atom is in an electric field, it is further perturbed because of the additional forces generated by the field. The application of an external electric field during the passage of the ionizing particle would then be expected to increase the number of atomic sites that have been permanently disrupted. It has been demonstrated (*2, 3*) that the specific ionization due to the incident particle must exceed a threshold value characteristic of the irradiated material in order to produce etchable tracks. It was anticipated, therefore, that it should be possible to use an externally impressed electric field to increase the damage and thereby enhance the production of etchable tracks.

We have examined the tracks created by alpha particles in cellulose nitrate. This polymer was chosen because it has a known threshold of specific ionization for the creation of tracks, corresponding to an alpha particle with an energy of 3 Mev. Alpha particles with energies greater than 3 Mev do not lose energy at a sufficient rate to leave etchable tracks in cellulose nitrate. We have used as a source of alpha particles Po^{210} which emits a 5.3-Mev alpha particle. The experimental arrangement is shown in Fig. 1. The alpha particles pass through a thin region of air (*5*) and then through a high-voltage grid before they strike a sheet of cellulose nitrate 0.25 mm thick. If we vary the distance between the source and the cellulose nitrate, the energy attenuation due to the air can be controlled. The alpha particles penetrate the cellulose nitrate to a depth of approximately 25 μm. The electric field is created by applying voltage between the high-voltage grid and a grounded grid placed on the other side of the cellulose nitrate. We have made tests with external fields varying from 0 to 1.8×10^5 volt/cm. After the cellulose nitrate samples have been irradiated, the samples are etched in a 6*N* solution of NaOH at 25°C for 2 hours.

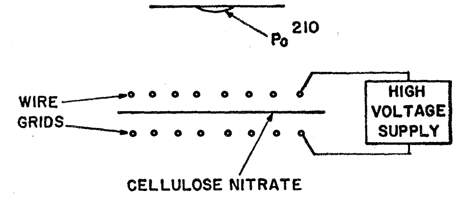

Fig. 1. Schematic view of the experimental apparatus used to enhance tracks created by alpha particles in cellulose nitrate.

The results reported here have been obtained with alpha particles which have passed through 1 cm of air. They strike the cellulose nitrate with an incident energy range of approximately 3.5 to 4.0 Mev. This spread in energy is due to variations in the path length of the alpha particles in air. As expected, in the absence of an electric field, alpha particles with an energy greater than 3.5 Mev do not create enough damage in cellulose nitrate to produce etchable tracks. However, when electric fields in excess of 6×10^4 volt/cm are applied, etched tracks become visible. We have attempted to estimate the efficiency of track formation by 4-Mev alpha particles in the presence of an electric field by comparing the number of tracks observed with those formed by 2.5-Mev alpha particles. With an external field of 10^5 volt/cm the track formation efficiency of 4-Mev alpha particles in cellulose nitrate is 80 ± 20 percent. This result is independent of the polarity of the electric field.

In the experiment reported here the electric field was applied roughly parallel to the path of the ionizing particles. One would not expect this field to change the net charge in an ion column created by passage of the alpha particle. Hence, the mechanism for the ion explosion spike would not be enhanced. The fact that track formation is enhanced supports the hypothesis that additional processes are important in the formation of etchable tracks, at least in cellulose nitrate.

By studying the nature of the track enhancement as a function of the strength of the electric field, and also as a function of the angle between the field and the particle forming the track, one should be able to gain a better understanding of the relative importance of the different mechanisms involved in the formation of etchable tracks. Possible applications of track enhancement through the use of an electric field are numerous. For example, it may be possible to construct a detector which would have the same spatial resolution as photographic films, but which could be "triggered" by the application of an electric field when an appropriate signal is received, much as spark chambers are operated.

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5. Fleischer *et al.* (*1*) have shown that the presence of oxygen during the initial process of track formation is essential to the reliable production of etchable tracks.
6. We thank Professors J. G. Brennan, T. E. Carew, R. W. Deutsch, F. L. Talbott, and Father E. M. Carreira for their cooperation. Supported in part by ONR contract N00014-67-A-0377-00021. F.J.K. is a NSF predoctoral trainee.

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Alaskan Upper Miocene Marine Glacial Deposits and the Turborotalia pachyderma Datum Plane

Abstract. *In southeastern Alaska the first marine evidence of widespread glaciation occurs in Miocene sections near the base of the Yakataga Formation. An associated temperature decrease of about 10°C is indicated by the influx of an upper Miocene cold-water planktonic foraminifer,* Turborotalia pachyderma, *an event that occurred about 13 million years ago.*

One of the most dramatic developments of the past one or two decades is the discovery of several kinds of evidence supporting major middle and later Tertiary polar glaciation—long before the onset of the classic Quaternary glaciations (*1*). Of utmost importance is the need to gather additional kinds of evidence concerning pre-Quaternary glaciations and to define precisely their times of occurrence. Evidences of marked pre-Quaternary climatic cooling have been noted in the middle Pliocene of Italy (*2*) and in the circum-Pacific area (*3*). An earlier cooling cycle has now been defined in the upper Miocene in Italy (*4*) and in other temperate areas (*3*).

In southeastern Alaska we have discovered a transition from warm- to cold-water planktonic foraminiferans near the boundary between the Poul Creek and the superjacent Yakataga Formations (Fig. 1). Further, the appearance of the cold-water planktonic fauna, *Turborotalia pachyderma* (Ehrenberg), defines the datum which Bandy and Ingle proposed as the boundary between the middle and upper Miocene of temperate and cooler-water areas (*5*) about 13 or 14 million years ago. In California this datum falls at the base of the Mohnian Stage; in Italy it is reported to fall at or near the base of the Tortonian (*6*); in New Zealand it would fall near the base of the Tongaporutuan (*7*). At this time *T. pachyderma* evolved from its immediate ancestor *T. continuosa* (Blow), according to Jenkins (*8*) and to our studies. Rare specimens of *T. continuosa* occur in the upper Poul Creek Formation at Cape Yakataga and at other locations.

Late Tertiary glaciation in Alaska, as represented by marine tillites of the Yakatage Formation, described by Miller (*9*), has been known for many years. Subsequent study has shown that the age of the Yakataga Formation spans much of the Miocene-Pliocene and has further defined the occurrences of the marine tillites (*10*). These marine tillites of the Yakataga Formation are evidently quite widespread; they extend more than 300 km along the southeastern coast of Alaska, centering at Kulthieth Mountain and Cape Yakataga (Fig. 1). Denton and Armstrong (*11*) have now obtained radiometric dates of volcanic rocks interbedded with nonmarine tillites from the north flank of the Wrangell Mountains of southeastern Alaska. They show that glacial deposits were being deposited there at least as early as about 10 million years ago. Further, some of the tillites they report fall within the interval between 8.8 and 2.7 million years ago. The latter may reflect the middle Pliocene cold interval recognized in temperate areas (*2, 3*).

A rather complete section of Tertiary rocks is exposed in the Yakataga district (*9, 10*), including the two principal Tertiary marine formations of concern here, the Poul Creek and Yakataga Formations (Fig. 1). The Poul Creek Formation, 1875 m thick, is Oligocene-Miocene, and is made up of marine sediments (shales and sandstones) with temperate or subtropical faunas. The superjacent Yakataga Formation, as much as 4574 m thick, is Miocene-Pliocene and is made up of many kinds of marine clastics including important marine tillites. It contains mostly cool- or cold-water molluscan faunas.

At the type section of the Yakataga Formation at Kulthieth Mountain (Fig. 1), the left-coiling *Turborotalia pachyderma* cold-water planktonic fauna (Fig. 2) appears abruptly about 50 m above the base of the exposed section; at nearby Cape Yakataga, the Poul Creek contact with the Yakataga Formation is exposed, and *T. pachyderma* first occurs there about 30 m above the contact. In both sections, thin conglomerates or glacial marine deposits make their appearance more or less in the same position and give