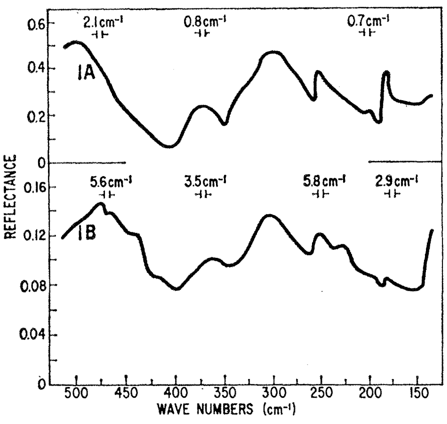

Fig. 1. Far-infrared spectra of fayalite in bulk (*A*) and powdered (*B*). The spectral slit widths used for various parts of the spectra are shown. The difference between the vertical scales of the two spectra accentuates minor features, possibly spurious, near 450 and 230 cm^{-1} in the lower spectrum.

constants of the medium. The incoherent volume scattering by the individual particles (that is, the Rayleigh scattering) is negligible compared with the surface reflection when the particles are very small compared with the wavelength. The reflectance at normal incidence is given by the modified Fresnel formula (*2*):

$$R = [(n-1)^2 + k^2]/\{[n + (2/f) - 1]^2 + k^2\} \quad (1)$$

where $n - ik$ is the complex refractive index of the material constituting the particles, and f is the fraction of the volume occupied by the particles. Equation 1 is valid only when the complex index is in the neighborhood of unity. We have derived a more general formula (based on the Lorentz-Lorenz theory) which is now under experimental test; the results will be published shortly.

Equation 1 shows that the reflectance has the usual bulk value when $f = 1$ and becomes smaller as f decreases. However, the shape of the spectral reflectance curve does not change significantly as the packing density decreases. For example, consider the change in R when k varies from 0 to 1, for a fixed value $n = 1.5$. When $f = 1$, R changes by a factor of 4.3; when $f = 1/2$, R changes by a factor of 4.8.

These conclusions are well demonstrated by the experimental results (*3*) shown in Fig. 1, which were obtained during a study of the far-infrared spectra (15 to 200 μ) of silicate minerals. The silicate in question was fayalite (Fe_2SiO_4), the iron-end member of the olivine series; the reflectance spectrum of a polished polycrystalline sample appears in Fig. 1*A*. When this material was ground to particles finer than 2.6 μ, with most particles smaller than 1 μ, and a surface was prepared from this powder, the reflection spectrum shown in Fig. 1*B* was obtained. The general reflectance level has clearly decreased, but the spectral shape has not greatly changed, although small shifts in some bands are apparent. In order to obtain this spectrum, it was necessary only to open the slits so as to increase the signal in comparison to the noise. As we have just shown, the less dense the material (that is, the smaller is f) the more this is necessary. The density of our material measured roughly 2.5 g/cm^3; the bulk density of fayalite is 4.14.

These conclusions also apply when the surface of the fine-grained medium is undulating rather than flat; the reflected radiation is then merely redistributed in angle, while the reflectance is unchanged. However, if the surface of the medium is covered with steep-walled cavities with dimensions of the order of the wavelength or larger, reflectance will be reduced because of multiple reflection. On the other hand, large internal cavities within the medium will in general enhance the reflectance by providing an incoherent volume scattering that adds to the surface Fresnel reflection. A reflectance formula has been given (*2*) that combines the effects of surface and volume reflection, whether the latter results from the presence of internal cavities or of large particles.

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22 December 1965

Tracers Determine Movement of Soil Moisture and Evapotranspiration

Abstract. *The downward movement of water in soil is a layered one. Marking a certain layer with hydrogen-isotope tracer, and watching its displacement, makes possible a water balance and gives information on evaporation and groundwater recharge.*

An investigation with natural deuterium and bomb tritium in groundwater, lysimeter-measured seepage water, and soil moisture (*1, 2*) has suggested that downward transport of water in soil is a very slow process and that the water may take years to reach the water table. Theoretical considerations (*2*) also led to the expectation that water seeping through larger pores has sufficient time for exchange with the stationary (capillary) water; lateral molecular diffusion provides for this exchange between draining and capil-

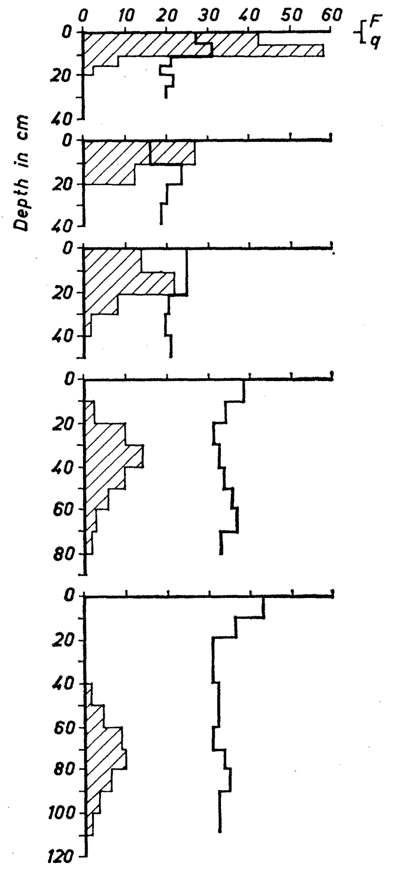

Fig. 1 (to be read in conjunction with Table 1). Loamy soil without vegetation, labeled 9 July 1964. *F* (heavy line), soil moisture (volume percentage); *q* (boundary of hatched area), amount of tracer per 10-cm layer of soil, as a percentage of the amount of tracer originally deposited in the soil; *a* to *e*, samplings 4, 26, 82, 152, and 214 days after labeling, respectively.

Table 1 (to be read in conjunction with Fig. 1). Moisture condition and tracer movement. Samples *a–e* refer to Fig. 1. Abbreviations: *R*, total precipitation after labeling; $\bar{F}$, average moisture between surface and tracer maximum; Σq (hatched areas in Fig. 1), total amount of tracer remaining; smaller near the periphery of the field because of lateral diffusion; *s*, distance of tracer maximum from the surface; γ, evaporation of precipitation subsequent to labeling; the fractional lag of the real progress of the tracer peak behind the maximum possible ($s_{\max} = R/\bar{F}$) gives the average evapotranspiration, $\gamma = s_{\max} - s/s_{\max}$.

Sample	*R* (mm)	$\bar{F}$ (vol. %)	Σq (%)	*s* (cm, ± 5)	γ (%)
a	16	25	100	5	*
b	28	16	40	5	*
c	101	27	40	15	60
d	247	35	45	37	50
e	384	35	40	70	35

* As long as the tracer peak remains near the surface, the uncertainty of *s* does not permit accurate calculation of γ; thus the tracer method cannot give reliable evaporation data for short periods, especially if concurrent precipitation is low.

lary water. Consequently, movement of soil water is "layered": new rainwater on the surface of the soil simply pushes the old water downward. Seepage water, which eventually shows up at a depth of 2 or 3 m, hours or days after a heavy rainfall, is in fact old capillary water, from soil layers immediately above, set free by a "pressure wave," the traveling velocity of which is equal to the seepage velocity of water in the wider pores.

A single "rainfall," labeled with isotope tracer (earlier we used heavy water; now we use tritiated water, which is much cheaper), forms a tagged layer of water that, although blurred by diffusion effects, moves downward as a distinguishable water mass between the older rainwater below and the younger rainwater above. After certain periods of time, small samples of soil are taken with a borer, and isotopic analysis of the soil moisture gives the vertical distribution of the tracer (Fig. 1 and Table 1).

For any period of time that is not too short, one can prepare a balance, for the soil above the tracer mark, between incoming rain, evaporation loss, and water that will eventually reach the groundwater table. An advantage of the method is that it provides detailed information on the water balance without disturbance of the natural conditions; it is applicable everywhere and cheaply.

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8 November 1965

Pottery Dating from Thermoluminescence

Abstract. *For pottery sherds from an arid region, the ratio of natural thermoluminescence to thermoluminescence induced by a standard dose of radiation corresponds closely to the independently assessed archeologic age. Difficulties in age determination, because of variations among sherds, are reduced by averaging results for samples from the same time period.*

Thermoluminescence (TL) is the release in the form of light of stored energy from a substance when it is heated. The phenomenon occurs in many crystalline nonconducting solids, and has been suggested as the basis of a dating technique for rocks and minerals (*1*). Naturally occurring radioactive elements in these materials are a nearly constant internal source of ionizing radiation. It is assumed that some of the electrons excited by this radiation become trapped in metastable states a few electron volts above the ground state. Released from their traps by heating, the electrons return to the ground state, emitting light.

Pottery accumulates such trapped electrons with time, and the amount of natural TL produced by a sherd therefore depends on the time elapsed since its last firing. The amount of natural TL also depends on the amount of ionizing radiation present, and on the nature and number of electron traps in the material (which determine the material's sensitivity to radiation-induced TL). By taking these factors into account, natural TL has been used for dating limestones, lava flows, ice, and pottery (*2, 3*). This report concerns application of a similar technique to a series of sherds from coastal Peru, where aridity reduces the effect of chemical and physical changes in the pottery that result from humidity.

The apparatus used for TL measurement has been described (*4*). A 50-mg sample of ground pottery is heated in a silver pan over a nichrome heating element to a temperature exceeding 400°C within a 1-minute heating cycle. The light output is detected with a photomultiplier tube, and the anode current is measured with an electrometer. The electrometer drives a T-Y recorder, which produces a graph of light output versus time (glow curve).

The height of the peak in the glow curve above the level of black-body radiation ($TL_{\max}$) is taken as the measure of the natural thermoluminescence. The sensitivity (*S*) of the pottery to radiation-induced TL is then obtained by measuring the TL produced by a standard dose (50 r) of 80-kv(peak) x-rays. The sensitivity is taken to be the height of the glow curve at the same temperature as $TL_{\max}$ (see Fig. 1). This region of the glow curve is relatively stable at room temperature, with a TL half-life at ambient temperatures of about 5000 years, as estimated from isothermal-decay measurements at higher temperatures. The large low-temperature peaks in the x-irradiated glow curves are not present in the natural-TL glow curves because the peaks decay rapidly at ambient temperatures.

In most previous work the thermoluminescent indicator of age has been $TL/(S \times \text{radioactivity})$. Previous measurements of radioactivity in pottery (*3*) have shown a low degree of variation between sherds (around 25 percent). Our preliminary work showed similar variation. The natural TL and *S* show much greater variation even