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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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

Table 1. Ratios of natural thermoluminescence to sensitivity (TL_{max}/S) for pottery subsamples of various present-day ages. Standard deviations of the means are given. Numbers of samples appear in parentheses. The Sechin Plain pottery is Colonial to Tiahuanaco in period; Salinas Plain, Late Classic; Patazca Polished Plain, Late Formative; Gualaño Black Plain, Middle Formative; Cahuacucho Thick Red, Early Formative.

Pottery		TL_{max}/S
Type	Age (yr)	(mean)
Sechin (6)	400–1100	.76 ± .27
Salinas (4)	1300	.98 ± .19
Patazca (4)	2400	1.90 ± .62
Gualaño (5)	2800	2.28 ± .77
Cahuacucho (3)	3000	2.21 ± .65

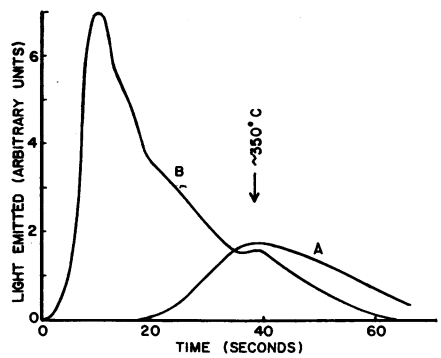

Fig. 1. Glow curves of the natural thermoluminescence (A) and of thermoluminescence induced by a standard x-irradiation (B) for a typical sherd; black-body radiation was subtracted from both. Arrow indicates the point at which both TL_{max} and S are measured.

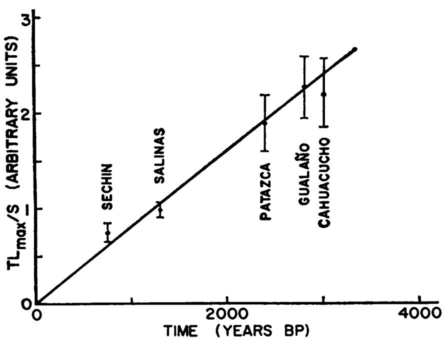

Fig. 2. Ratio of natural thermoluminescence to sensitivity (TL_{max}/S) plotted versus the age of the pottery. Means for the pottery subsamples are represented by dots; bars indicate standard errors.

among sherds from the same site. To get a better value for the age indicator it was decided to concentrate on measuring the parameters that varied the most: thus the TL_{max} and S were measured for several samples from the same area, and the average TL_{max}/S was taken as an indicator of age. This method eliminated the costly and time-consuming process of measurement of total radioactivity.

Thermoluminescence not induced by radiation, probably resulting from grinding stresses, appeared to constitute about 10 percent of the natural-TL light output; no correction was made. The samples were not heated in a nitrogen atmosphere to reduce this TL not induced by radiation (*3*).

All sherds were from the Casma Valley. The ages of the pottery samples are derived from published reports on the area (*5*) and from sherd assignment by the archeologic workers. The archeologic dates are based chiefly on considerations of stratigraphy and on one C^{14} date (*6*).

The TL_{max}/S values for samples of the pottery series (Table 1) are plotted versus age in Fig. 2. Table 1 shows that there is a standard deviation of around 30 percent for the TL_{max}/S of samples from the same time period. Despite this scattering, the means for the samples from the same time period show a high degree of correlation ($r = .99$ for $n = 5$) (*7*) with the archeologic age, and even the correlation between the values for individual sherds and age is high ($r = .79$ for $n = 22$).

These limited data indicate that the ratio of natural TL to sensitivity is a fairly accurate indicator of archeologic age, especially when averaging is used to obtain a better mean for sherds from the same time level. Part of the variation within samples from the same time period in this series may reflect the omission of radioactivity determinations, but Aitken *et al.* (*3*) found similar variations even when account was taken of radioactivity. The close association between age and the TL indicator of age in our work therefore may result from the relatively arid location of these sherds, as well as from the averaging procedure.

Many factors affect the nature and extent of thermoluminescence, and experimental control of all of them is impractical. Our results suggest that averaging techniques may be effective in dealing with these factors; they further indicate the potential usefulness of thermoluminescence dating in archeology.

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6. The C^{14} dates on Cahuacucho and Gualaño shells indicate an apparent instance of reversed stratigraphy, which makes the dates unacceptable to the archeologist in charge.
7. A TL_{max}/S of 5.35, determined on one Middle Jomon sherd of the Nakano type from Shikimu Town, Hokkaido, indicates substantial age. The estimated age, derived from the regression of archeologic age on TL_{max}/S of the grouped data depicted in Fig. 2, is 7192 years. The archeologic age of the sample is given as around 7000 years.

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Intermuscular Bones in Pholidophorus bechei from the Lower Lias of England

Abstract. *Intermuscular bones, considered the one neomorph which decisively separates the pholidophoroids from the teleosts, have been found in a specimen of* Pholidophorus bechei *Agassiz, from the Lower Lias of England. It is suggested that intermuscular bones were prevalent among the pholidophoroids.*

The teleost fishes have been characterized as incorporating several improvements in the locomotor mechanism which distinguish them from their presumed ancestors, the Mesozoic Pholidophoriformes (*1*). Among these improvements, none has been regarded as more consistent or more decisive than the origin of intermuscular bones among

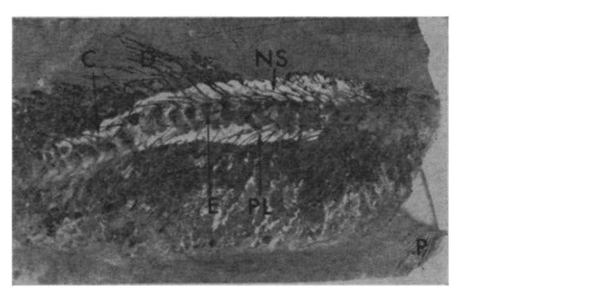

Fig. 1. Abdominal and anterior caudal region of *Pholidophorus bechei* (AMNH No. 6300). Abbreviations: *C*, first caudal vertebra; *D*, dorsal fin; *E*, epineuralia; *NS*, neural spine; *PL*, pleural rib; *P*, pectoral fin.