from the west (142°E) almost to the Galápagos (92°E), where, in the vicinity of Albemarle Island, its speed diminishes and the core deepens. Toward the east of the archipelago this undercurrent is not very significant, and the further distribution of the large volume of water is unknown (see *7*).

The results of our study are given in Table 1 and a geographic comparison by map in Fig. 1 (*8*). Apparently, conditions on the coasts of Chile and Peru correspond to conditions along the Mexican coast where an effect of -240 ± 80 years or -3.0 ± 1 percent relative to 0.95 the count rate of the National Bureau of Standards oxalic acid for radiocarbon laboratories (contemporary biospheric standard) is observed. The shell sample from Costa Rica (UCLA-1254) fits into an extension of the prevailing values along the Mexican coast. However, in equatorial latitudes of Panama and Ecuador a deviation of only about -100 ± 80 years or -1.2 ± 1 percent seems to apply. It is interesting to note how the trend in the radiocarbon content of the shells follows the large-scale pattern of ocean currents.

Conditions similar to that encountered in and near the Gulf of California, with a maximum of -7.06 percent, can occur on the Peruvian coast where a -8.5-percent value was obtained. Such high fluctuations stress the need for careful study of the marine environment from which shells in archeological sites may have originated (*1*).

Although there is limited knowledge of the archeology of the Galápagos Archipelago, so far no evidence of a permanent prehistoric population of man has been found, and there is serious doubt that there ever will be because of the notorious lack of a supply of fresh water. Occasional visits from the South American mainland by balsa rafts, however, appear to have occurred long before the discovery of the islands by de Berlanga, Bishop of Panama, in A.D. 1535 (*9, 10*). For marine shells from Galápagos, a difference from biospheric land carbon of -0.35 to -4.04 percent appears to be typical, and this should be taken into account when anthropological or geomorphological samples are dated. In other words, deviations as high as about 300 years or so may be encountered. Consequently, it would be necessary to restrict carbon-14 sampling to stratigraphic increments whose true ages differ by more than 300 years. Similar considerations apply to other mainland beaches where ranges in the specific activity of shells are encountered (*11*).

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Landslide Noise

Abstract. *Acoustical monitoring of real landslides has revealed the existence of subaudible noise activity prior to failure and has enabled prediction of the depth of the seat of sliding when conducted in boreholes beneath the surface. Recordings of noise generated in small slopes of moist sand, tilted to failure in laboratory tests, have been analyzed to determine the foci of discrete subaudible noise events. The noises emitted shortly before failure were plotted close to the true sliding surface observed after failure. The foci of earlier events lay either within the central portion of the sliding mass or in a region behind the failure surface. The head and toe zones were devoid of strong seismic activity.*

The transient, audiofrequency, sonic oscillations that emanate from such varied materials as metals, ice, rocks, and soils when they are strained elastically have been referred to as microseismic, seismoacoustic, elastic-impulse, or subaudible noise activity. While considerable research, begun by Obert (*1*), has been devoted to the subaudible noises associated with mining and other underground works, there has been little application of this technique until recently to surface phenomena such as landslides. Since both American (*2*) and Russian (*3*) scientists have achieved reasonable success with the subaudible technique for forewarning of failures or rock bursts underground, the possibility of predicting landslides and slope failures was investigated. In addition Japanese (*4*) and Americans (*5*) have been studying the method as a possible means of predicting earthquakes.

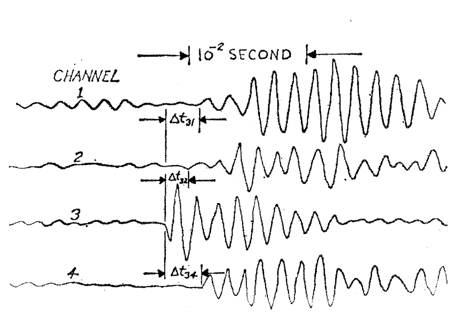

Fig. 1. Recording of a subaudible event generated within a small-scale landslide and received by four piezoelectric transducers, showing the three time delays. The ring-down is the natural frequency of the cantilever-mounted transducer (580 cycle/sec), and not a characteristic of the subaudible noise.

Fieldwork on existing landslides revealed the presence of subaudible noises and noted a rough correlation between the noise rate and the stability of the slope once the local background rate was known (*6*). The depth to the seat of sliding has been successfully identified from relative noise rates in a borehole in a landslide. However, attempts to locate the source of the noises with arrays of noise detectors on the surface, were frustrated by high levels of background noise, poor coupling between geophores and the landslide mass, the rapid attenuation of the seismic energy—especially the higher-frequency portion—and finally the extreme heterogeneity of most landslides studied (*7*). In an effort to determine the precise origin of the noises and so direct future field activities, laboratory experiments were conducted on small slopes of moist sand (*8*).

A tilting box, 60 by 60 by 124 cm, was filled with a uniform, partially saturated beach sand. Vertical, red-dyed layers of sand were built into the 45° slopes to depict the sliding surface, and four highly sensitive Rochelle-salt, bender, crystal transducers were placed within the sand at known coordinates. The velocity of the sand was determined, and the slope was tilted slowly to failure while the output of the geophones was recorded on magnetic tape. By playing of the tape through a high-frequency response oscillograph, selected events could be broadened and first-arrival points picked for each of the four channels in order to yield three delay times (Fig. 1).

To calculate the focus coordinates for each event, it is necessary to know the compressional wave velocity of the sand, c; the coordinates of each of the probes, x, y, and z; and finally the three time delays, Δt_{ij}, where i is the channel of first arrival and j represents the remaining channels. The general equation is

$$\begin{aligned} f_j(x_j,y_j,z_j) &= c\,\Delta t_{ij} - \\ &- \sqrt{(x_j-x_0)^2+(y_j-y_0)^2+(z_j-z_0)^2} \\ &+ \sqrt{(x_i-x_0)^2+(y_i-y_0)^2+(z_i-z_0)^2} \end{aligned} \quad (1)$$

where the three functions $f_j = 0$ if x_0, y_0, and z_0, the coordinates of the focus, are specified precisely.

Although there are three simultaneous equations for the three unknowns, the expressions are nonlinear, and explicit solutions could not be obtained. Newton-Raphson iteration was used to solve the equations. If the first guess of the focus coordinates is close, then

$$f_j = f_j(x_0 + u_x, y_0 + u_y, z_0 + u_z)$$

where u_x, u_y, and u_z are the x, y, and z distances from the guesses to the real coordinates of the focus. The first terms of a Taylor expansion of the above yield

$$\frac{\partial f_j}{\partial x_0} u_x + \frac{\partial f_j}{\partial y_0} u_y + \frac{\partial f_j}{\partial z_0} u_z - f_j = 0 \quad (2)$$

Differentiation of Eq. 1 and substitution into Eq. 2 give a set of three equations

$$\{f_j\}_I = (B_{ij})_I \{u_j\}_I \quad (3)$$

where $\{f_j\}_I$ is the vector containing the three functions for the first guess of the focus coordinates, $(B_{ij})_I$ are the nine terms calculated by use of $< x_0, y_0, z_0 >_I$, and $\{u_j\}_I$ is the vector of correction terms that will yield a refined guess $< x_0, y_0, z_0 >_{II}$.

A computer program was written to handle the extensive computations involved and to repeat the process until convergence (*9*). Since the first guess had to be sufficiently close to the true focus coordinates for convergence to be able to take place, a string model was built to provide an accurate first approximation of the focus coordinates (see *10*).

Initial tests with air-dry sand were unsuccessful, since the raveling of sand grains on the surface of the slope obscured the noise generated at depth, and a well-defined sliding mass was not developed. Subsequent tests on partially saturated sand yielded satisfactory results: in several of the tests, the sliding mass was caused to move more than once, so that intermovement noises could be recorded.

All noise events studied were arbitrarily divided into noises that occurred just before (within 10 seconds of) failure—thus at low factors of safety—and events occurring earlier at higher factors of safety. The experimental results indicate that the foci of noises occurring just before failure lie statistically much closer to the real failure surface than do those of the earlier noises (Fig. 2). Most of the noises associated with high factors of safety were generated from the region behind the failure surface when tension cracks were observed in the head area, but from within the sliding mass when no tensional features were observed. It ap-

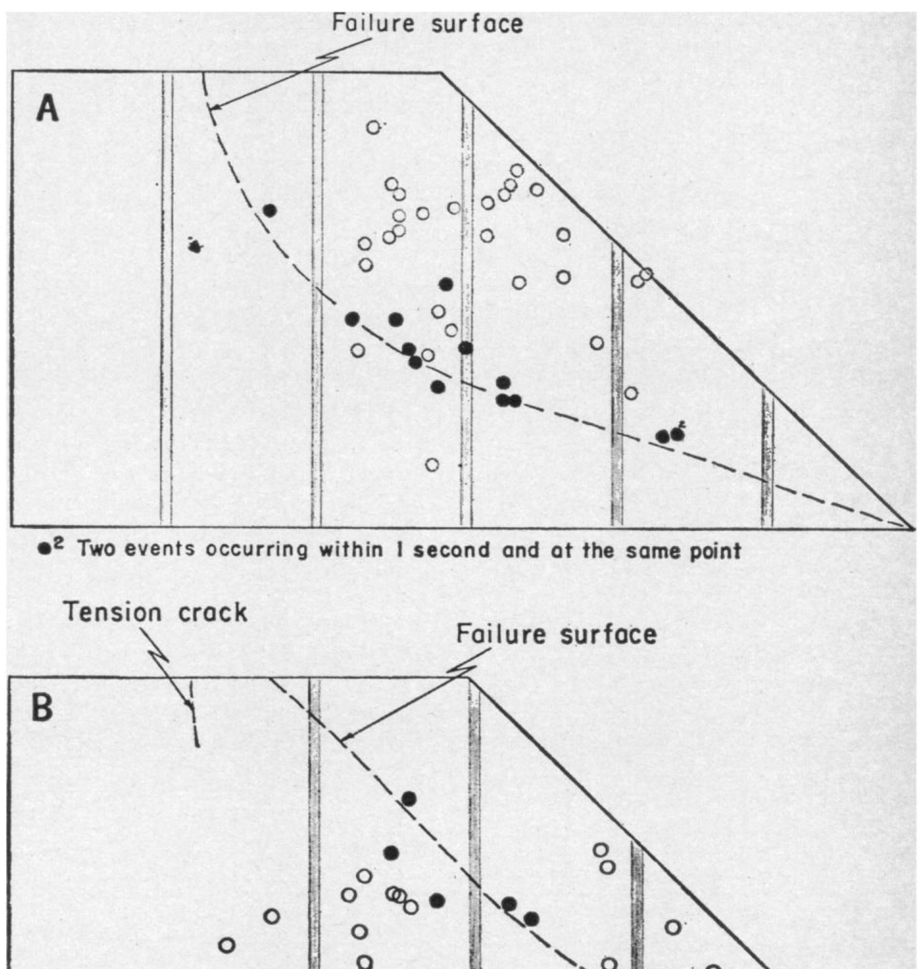

Fig. 2. (A) Profile of a thick slide developed in a tilting box in the laboratory, showing the location of the noises generated at high factors of safety (open circles), lying mostly within the slide. The noises at low factors of safety (black circles) lie close to the failure surface. (B) Profile of a thinner slide, showing most of the very early events lying behind the failure surface and probably associated with the tension crack. The noises generated just before failure again plot close to the failure surface. Gray verticals are layers of red sand.

pears likely that the tension cracks and noises located behind the true failure surface indicate the development of potential, though ultimately more stable, shear surfaces. The head and toe zones were notably free of comparable noise activity. On several occasions two or three noises occurring within a few seconds of each other were located within 2.5 cm of each other (Fig. 2); this phenomenon has been described as a chain-reaction microfailure.

These studies in the laboratory and in the field have important practical connotations. Fieldwork demonstrated the ability of a survey of rock noises to identify the active portions of a large landslide and to locate the depth of the seat of sliding from relative noise rates in a borehole through the slide. Laboratory study of noises from small-scale landslides demonstrated that noises occurring shortly before failure originate from the central part of the surface of sliding that later develops; this result suggests that arrays of conventional seismic geophones on the ground surface may be able to define the geometry of an impending landslide even before it occurs.

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Splashing of Drops on Shallow Liquids

Abstract. *The events that follow the splashing of a drop on a liquid depend on the depth of the liquid. When the depth is less than about 5 millimeters the crown that is ejected is more unstable than that from a splash on a deep liquid. As the depth is decreased from 25 to 7 millimeters, there is an increase in the maximum height to which the Rayleigh jet rises, and in the number of drops that break away from the jet. With depths less than 7 millimeters these two quantities fall off sharply, and no jet drops are produced for depths less than about 3 millimeters.*

The sequence of events following the collision of a liquid drop with the surface of a deep liquid have been photographed and described (*1, 2*). Comparatively little work has been done, however, on the splashing of drops on shallow liquids, although this phenomenon plays an important role in soil erosion and the dispersal of seeds and microorganisms by raindrops (*3, 4*). Gregory *et al.* (*4*) investigated the splashing of water on thin films of spore suspensions and found that the number of splash droplets increased markedly as the thickness of the film decreased from 1 to 0.1 mm; they did not investigate changes in the nature of the splash with decrease in depth of liquid. We now describe modifications that occur in the Rayleigh jet and in the crown as the depth of liquid into which a drop splashes is progressively decreased.

The incident drops were produced by forcing liquid at a constant pressure through a 26-gauge stainless steel hypodermic needle; their diameters varied from 2.4 to 3.8 mm, with the distance of fall always 75 cm. The liquid into which the drops splashed was contained in a 45-cm square tank, 25-cm high. In addition to the permanent base, the tank had a false base that could be positioned at any level within it, so that quick and accurate changes could be made in the effective depth of liquid without addition or removal of liquid. Photographs were taken with a high-speed 16-mm camera that was generally operated at 1000 frames per second.

Because a mixture of milk and water gives good contrast against a dark background, it has been commonly used for photography of the splashing of drops on liquids. In the first series of experiments the incident drop and the liquid in the tank consisted of a

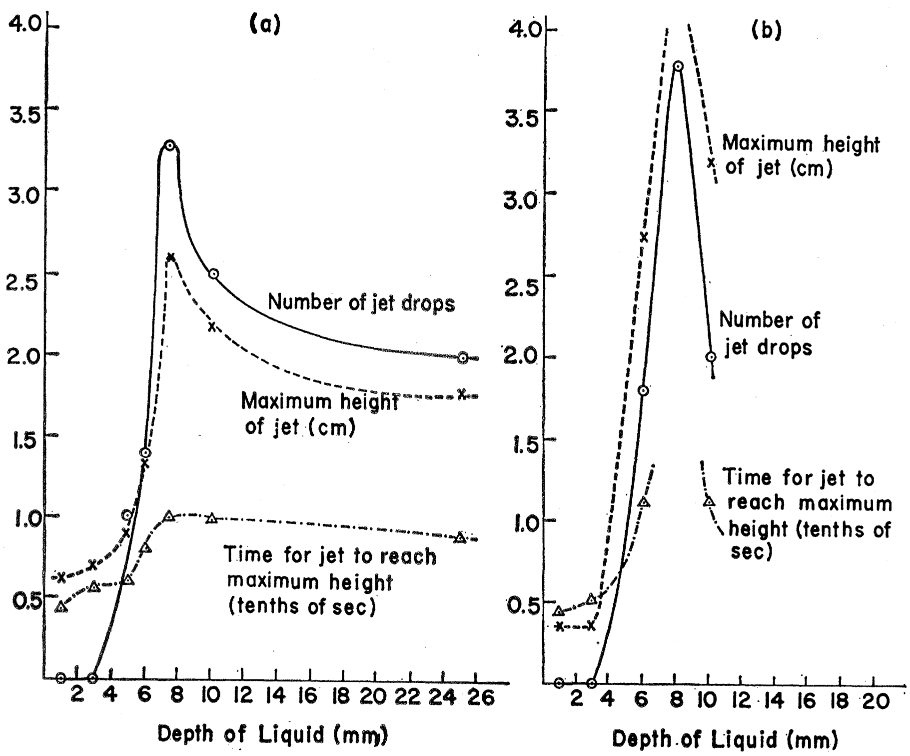

Fig. 1. Data on the Rayleigh jets produced by drops, 2.4 to 3.8 mm in diameter, falling 75 cm on milk-water (a) and dyed water (b).