dark gray in long-wave flux—correspond to the sensation green. The lightnesses of the door—light gray in long-wave, dark gray in middle-wave flux—correspond to the sensation red.

To provide a better description of the color sensations, the observers were asked to study the awning and the door, and then to select from the *Munsell Book of Color* (*9*) a chip that most closely matched their memory of the awning and the door. The *Munsell Book of Color* was viewed with a Standard Illuminant C in an otherwise darkened room. If the observers could not find a suitable chip, they were instructed to estimate the designation of a chip that would match the awning or the door. The Munsell chips chosen are listed in Table 2.

In the second experiment the *Street Scene* was replaced by a multicolored paper display called a "Mondrian." This display was made of matte-surface papers, cut and overlapped to form squares, rectangles, polygons, and other shapes. There were 23 papers and the entire display subtended roughly 36° on a side. The areas studied were rectangular and their diagonals subtended roughly 8°. New wedge transparencies were chosen so that the same flux came to the eye from these two areas in 656-nm light and 546-nm light. As in the first experiment, the entire display was below cone threshold for 546 nm. Table 3 shows that the two areas studied by the observers were one-sixteenth the amount of light necessary to obtain a threshold response from the middle-wave cones.

Six observers were once again used for this experiment. They were asked to describe the lightnesses of the two areas as white, light gray, middle gray, dark gray, or black, first in long-wave and then in middle-wave light. As in the previous variation of the experiment the observers were asked to find the Munsell chips that most closely matched the two areas. The Munsell chips chosen are shown in Table 4. The observers reported that the area on the left in 656-nm illumination was light gray and that in 546-nm illumination was also light gray. The area on the right was middle gray in 656-nm light and dark in 546-nm light. In combined 656- and 546-nm light the observers reported that the area on the left side was yellow and the area on the right was dark brown. Again the identical sets of radiances would not predict this outcome, namely, that the color sensations will be different. However, above cone threshold, yellow areas always appear light in both long- and middle-wave flux. Brown objects always appear dark in both wave bands, but somewhat lighter in long-wave flux.

In two similar experiments the illumination was controlled so that the displays were below cone threshold for 546-nm light and slightly above cone threshold for 656-nm light. The observers saw a variety of colors from the interaction of rods and long-wave cones. In each wave band the illumination was controlled so that the same amount of light came from the particular low-reflectance objects that appeared dark and high-reflectance objects that appeared light. When the rods and long-wave cone images were combined, the observer reported different color sensations—red versus green and yellow versus brown—from areas that were identical physical stimuli. The color sensations produced by these rods and long-wave cone interactions support the hypothesis that lightnesses on independent systems determine color sensations.

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4. In these experiments I always worked with two wave bands of illumination and hence I only discuss two lightness scales. Land's retinex theory proposes that there are three or four independent lightness images. In other experiments Land has used three projectors with the *Street Scene* experiment. The position of the short-wave footlight was chosen so that the same short-wave flux came from both areas. Both the awning and the door appeared dark in short-wave light.
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10. I thank E. H. Land for comments and advice and Marie Watson for help with the experiments and the report.

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Submarine Seeps: Are They a Major Source of Open Ocean Oil Pollution?

The existence of submarine seeps is often mentioned in discussions of oil pollution. The argument is made that natural seeps might be of equal importance to man's action in fouling the high seas and the beaches, or that marine organisms which have survived these natural seepages will also survive oil pollution caused by man. Therefore, it is important to assess the relative contribution of seeps and of pollution to marine "tar" (crude oil lumps). I believe that an estimate of some reliability is possible.

According to Weeks (*1*), a maximum of 700 billion barrels of the world's ultimate resources of offshore oil is available by primary recovery; as much as 10 percent of this represents natural gas liquids. Thus, 630 billion barrels (or $100,000 \times 10^6$ metric tons) is the maximum amount of offshore oil that is a likely source of submarine seeps. The additional 300 billion barrels of oil which are accessible to secondary recovery do not contribute to seepage; in fact, the estimate of 630 billion barrels is high, since it includes oil which is not free flowing but can be recovered only by pumping.

Estimates for the amount of petroleum reaching the oceans from all sources vary; an influx of 0.5 percent of the annual oil production has been quoted (*2*). In view of the amount produced in 1970 (2200×10^6 tons), this would amount to 11×10^6 tons. Most estimates range close to that figure, between 1 and 10×10^6 tons (*3*).

For the sake of argument, let us assume that the seepage equals in tonnage the oil pollution from human activity, which we will put at 5×10^6 tons. This would imply that submarine seepage would deplete the ultimate reserves of freeflowing offshore oil in less than 20,000 years.

Crude oils are geologically ancient, and the oil formation potential of the source beds is finite. Petroleum ranges in age from Pliocene (2×10^6 years) to Ordovician and Cambrian (4 to 6×10^8 years). A typical average age may be mid-Eocene (5×10^7 years). If annual submarine seepage had averaged 5×10^6 tons since the early Tertiary, the average offshore oil field would have lost to the oceans 2500 times the free flowing oil or more than 1500 times the total oil existing in situ before commercial offshore oil production started.

This implication is geologically and geochemically untenable and suggests that either submarine seepage has accelerated, by orders of magnitude, during the present century (which is unlikely) or that seepage is orders of magnitude less, on a worldwide basis, than the oil pollution caused by man (which is possible and probable).

Seeps occur on land as well as under water. This has been used in exploration, not only in the ocean, but also on land. However, in general, oil reservoirs are well sealed even on the continents where uplifting and erosion should have bared oil-bearing strata more extensively than on the ocean floor. Oil leaking to the sediment surface frequently forms an asphalt seal through loss of the most volatile and most soluble components, and through oxidation and polymerization of the residue.

Crude oil lumps ("tar balls") are now universal constituents of the surfaces of the world oceans, and there is good reason to believe that most of these are the result of man's activities.

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Tidal Triggering of Moonquakes

Latham *et al.* (*1*) recently presented evidence of moonquakes recorded by sensors at the Apollo 12 landing site between December 1969 and December 1970 inclusive. They correlated these with the anomalistic cycle (variation of the distance between the moon and the earth) and found that moonquakes usually occurred within a few days of perigee or, less frequently, apogee. They illustrated this conclusion by plotting the interval of time between perigee and the occurrence of the first seismic event (A_1 category) of each month (A_1 events were those occurring in the most active seismic zone, about 600 km south-southwest of the station). They showed that first A_1 events of the month (presumably they meant the anomalistic month) occurred 6 days or less before perigee. While I was unable to understand their conclusions regarding the observed variation of monthly seismic energy release, I do agree with their main conclusion that moonquakes are triggered by tidal stress.

Their report would lead one to believe that moonquakes are triggered by the anomalistic lunar tide, but the latitudinal (or declinational) tidal wave, which they did not mention, would be an equally likely candidate as a trigger. The anomalistic tide consists of the lunar tidal bulges shrinking and expanding during approach to apogee and perigee, respectively. The latitudinal (or declinational) tide consists of northward and southward movement of the tidal bulges about the lunar equator during approach to maximum negative and positive lunar latitude (or maximum positive and negative earth declination from the lunar equator), respectively. The latitudinal displacement of the lunar tidal bulges is $10° \pm 3°$ about the lunar equator and occurs because the moon's orbital plane is inclined about 5° to the ecliptic. The amount of latitudinal displacement varies because the moon's rotational axis is inclined about 1.5° from the normal to the plane of the ecliptic.

The theoretical height of the lunar tide caused by the earth is proportional to $(3 \cos^2 Z - 1)/r^3$ (*2*), where Z is the zenith angle of the earth as seen from a point on the moon, and r is the distance between the earth and the moon. A few calculations show that the anomalistic tidal amplitude is greatest at the equator (somewhat smaller at the poles) and zero at 55°N and 55°S latitude. The latitudinal tidal amplitude is quite small at the equator (and at the poles) and greatest in the middle latitudes. Moreover, the maximum latitudinal tidal amplitude (at 55°N or 55°S latitude) is nearly equal to the maximum anomalistic tidal amplitude (at the lunar equator). The two are about equal at 25°S, the approximate latitude of the A_1 seismic zone.

A combined latitudinal-anomalistic tidal triggering mechanism is supported by the data of Latham *et al.* (*1*). By taking their times of first A_1 events of the month from the graph of time interval from perigee one can, with *The American Ephemeris and Nautical Almanac* (*3*), find the approximate values of lunar latitude (angular distance from the ecliptic plane) corresponding to those times. For the purpose of this cursory investigation lunar declination, rather than latitude, was used because it is tabulated more completely in the *Ephemeris* and because the declinational and latitudinal cycles were very nearly synchronized in phase in 1970.

All of the first A_1 events of the month occurred within 1.5 days (compared with 6 days for perigee) of the time of maximum negative lunar declination ($-\delta_L$ max) and perhaps even closer to the times of maximum negative lunar latitude. All but two of the first A_1 events occurred just after $-\delta_L$ max. The other "perigee" moonquakes clustered around the time of $-\delta_L$ max, and the "apogee" events corresponded very closely to times just after $+\delta_L$ max. The original and subsequent data should be carefully studied to check this preliminary result.

Because most of the A_1 moonquakes occurred when the earth was about 5° north of the mean lunar equator at about the time of perigee it appears that they were triggered by deformation in a plane almost exactly intermediate between the major and minor axes of the lunar stress ellipsoid, that is, by shear.

Latham's data show a general tendency for the total monthly seismic energy (and the peak 48-hour energy) to be greatest around the time of summer solstice with a secondary maximum around winter solstice. During the equinoctial months (except perhaps in the spring) the moon was seismically relatively quiescent. Except for the springtime activity this is what would be expected, because at $-\delta_L$ max the sun and the earth would pull in conjunction in June and in opposition in December, and neap tides would coincide with quadrature at the equinoxes.

It will become easier to distinguish the moonquake triggering potential of the various lunar tides as the declinational, anomalistic, and latitudinal cycles continue to move out of the situation of near phase-synchronization that existed in 1970. It is very encouraging