nual 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 to see this additional evidence of a tidal triggering mechanism, because a similar process appears to trigger terrestrial volcanic eruptions (*4*), and perhaps earthquakes as well (*5*). The terrestrial situation is somewhat obscured, however, because of the complicating loading effects of oceanic and atmospheric tides, ocean currents, and atmospheric circulation. The moon has provided another clear, albeit luxurious, view of the earth.

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Hamilton (*1*) has proposed that a combined latitudinal-anomalistic tidal triggering mechanism for moonquakes is supported by the data presented by Latham *et al.* (*2*). We agree that the anomalistic and the latitudinal tides are equally likely tidal triggering mechanisms (*1*), but, for reasons stated previously, we feel that the repeating moonquakes, designated category A, are primarily triggered by the anomalistic tide.

The identification of a particular tide as the primary triggering mechanism of category A moonquakes is based on the correlation between observed parameters, such as occurrence times of moonquakes and long-term variations in both moonquake occurrence times and energy release, and the theoretical variations in amplitude or phase (or both) of the suspected tidal component. Moonquakes should not necessarily be expected to coincide with maximum or minimum tidal amplitude, but they should occur with some consistent relationship to the amplitudes or phases (or both) of the triggering tidal component. Likewise, temporal changes in moonquake occurrence characteristics should be systematically related to changes in the triggering tide. If moonquakes represent shear dislocations along fault planes, the relative orientations of the fault planes and the principal tidal stresses would be a critical factor for the triggering of moonquakes. With no prior knowledge of the lunar global stress pattern or the orientations of the active faults, it is difficult to specify moonquake triggering mechanisms.

As shown by Latham *et al.* (*2*), category A moonquakes occur, with few exceptions, at monthly intervals near the time of perigee, with a secondary peak in activity near apogee. Category A perigee moonquakes account for over 95 percent of the category A moonquake energy observed at the Apollo 12 seismic station, with the largest subset, category A_1, accounting for about 80 percent of the total. The total monthly energy release varies with a period of 213 days, which agrees very well with the theoretical 7-month gravity cycle of the anomalistic tide. Also, the activity begins latest during months when the maximum energy is released. No effects of a latitudinal tidal triggering mechanism can be verified for the period 20 November 1969 to 1 January 1971 because the anomalistic and latitudinal tidal cycles were nearly in phase during that interval (*1*). A preliminary analysis of additional data has revealed that the largest category A moonquakes continue to occur near perigee through September 1971. These occurrence times correspond to about 6 to 7 days after the maximum northern latitudinal libration.

Thus, the data suggest that the category A moonquakes are primarily triggered by the anomalistic tide. The latitudinal tides may act as a secondary triggering mechanism. Such a "coupling" might better account for the observed variation in the category A total seismic energy release at perigee for the periods February to April and September to November 1970 (*2*) than does the influence of the solar tides, which is suggested by Hamilton (*1*), since the amplitude of the solar tidal component is only 1 to 3 percent of the amplitudes of the earth-generated tides (*3*).

A second type of moonquake, designated category B, has recently been identified (*4*). Preliminary data analysis suggests that the tidal triggering mechanism of category B moonquakes is different from that of category A moonquakes.

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Obsidian Hydration Dating Applied to Basaltic Volcanic Activity

Friedman (*1*) and Friedman and Smith (*2*) pioneered a valuable reconnaissance tool with their development of hydration-rind dating of obsidian, and Peterson and Groh (*3*) and Friedman and Peterson (*4*) made a good selection of an area in which to apply the technique when they chose Newberry Volcano, Oregon, with its variety of young volcanic rocks.

We have been involved in studies of Newberry Volcano during the past 5 years (*5–8*) and, thus, have special interest in the dating of these young volcanic rocks. Therefore, we feel compelled to point out that two of the reported dates are surely erroneous and to urge caution in the application of the hydration-rind technique to deposits that may have been subjected to hydrothermal or solfataric activity.

There are six young, rhyolitic obsidian flows in Newberry Caldera (*5*). Peterson and Groh (*3*) published hydration-rind ages for five of these flows and a ^{14}C age for charred tree wood from a pumice deposit that extends beneath one of the obsidian flows, commonly called the Big Obsidian flow. Their ^{14}C age agrees well with the hydration-rind age that they obtained for the Big Obsidian flow, and in light of relative ages based on geologic field relations, that age and the hydration-rind ages of three of the other obsidian flows as well, seem reasonable to us. However, the geologic relations and other ^{14}C ages indicate that Peterson and Groh's (*3*) hydration-rind age for the small obsidian flow in the crater of Central Pumice Cone (their Pumice Cone Crater Obsidian Dome) is greatly in error. This obsidian flow is in the bottom of the symmetrical crater of