THERMAL MOONQUAKES AND BOOMING DUNES

David R. Criswell - Lunar Science Institute, 3303 Nasa Road 1, Houston, Texas 77058
John F. Lindsay - La Trobe University, Bundoora, Victoria, Australia 3083

Lunar surface microseisms ($f \approx 4$-8Hz & $0.2 < A(nm = 10^{-9}m) < 2$ vertical amplitude, $\bar{A} \approx 0.6$nm) have been detected (1). Most of these events, which originate within a radius $r < 4$ km of a given ALSEP station, are thought to be produced by the thermally induced slumping of lunar soil on steep slopes such as those on Cone Crater (A-14) or at Hadley Rille and Mount Hadley (A-15). This interpretation, if qualitatively correct, means that the short period seismometers (A-11, 14, 15 & 16) and geophones (A-17) at these Apollo sites monitor local non-meteoritic surface erosion rates in real time. The key question is "How is the total energy (E_o) of each slumping event related to the amplitude of the observed microseism?" Booming dunes are rare terrestrial dunes whose sands emit a very low frequency ($f < 100$Hz) noise and/or note during slumping. Very efficient conversion of slumping energy into vibrational seismic energy has been observed (2). It has been suggested that lunar slumping events might also boom because the booming process could reduce the lunar erosion rates inferred from thermal moonquakes by 10^6 to 10^9, could provide a simple explanation for the repetition of complex slumping patterns from one lunar day to the next, and be consistent with the narrow bandwidth of the thermal moonquakes (3).

Surface explosions over a range of detector/explosion separations were employed in the Active Seismic Experiment (ASE) to establish an empirical relation between disturbance energy (E_o(ergs)), A(nm), and r(km)

$$E_o = r^2 A^2 / K^2 \qquad (1)$$

where $K = 7 \cdot 10^{-7} \frac{\text{nm-km}}{\text{ergs}^{1/2}}$ (4; 5). Enormous erosion rates would be required to sustain the observed thermal moonquake activity at Fra Mauro if this small a value of K were applicable to slumping-to-seismic energy conversion. To illustrate, assume slumping inside Cone Crater ($r \approx 1.5$km, $\bar{A} \approx 0.6$nm) produced the 350 events presently observed each lunar day. The total annual release of energy would be $7 \cdot 10^{15}$ ergs which means that $V \cdot h = 2 \cdot 10^{13} cm^4$/year where $V \sim$ the volume and $h \sim$ the decrease in center-of-mass height of the slumping material (slumping energy = $Vh\rho g_1$, $\rho = 2 gr/cm^3$, $g_1 = 167 cm/sec^2$). At this rate the interior slopes of Cone Crater (diameter ≈ 350m) would be reduced by 5° from their maximum possible inclination (dynamic angle of repose $\approx 35° - 40°$) to less than their static angle of repose in the order of 10^2 years.

THERMAL MOONQUAKES

Criswell, D. R. & Lindsay, J. F.

Exposure ages of $3 \cdot 10^7$ years or $3 \cdot 10^5$ slumping periods ($\approx 3 \cdot 10^7 / 10^{+2}$) have been ascribed to Cone Crater ejecta (6). Adjustment of K upward by factors of 30 to 100, in analogy to the greater seismic coupling efficiency of earthquakes than surface explosions only marginally reduces this dilemma (1). However, if a lunar "booming" process operated at only 5% efficiency K could be multiplied by approximately 7000 and slumping rates would be multiplied by $2 \cdot 10^{-8}$ (i.e. $5 \cdot 10^9$ years for 5° slump of interior walls of Cone Crater). Booming events of $2 \cdot 10^4$ ergs would suffice rather than the 10^{12} ergs implied by eq. (1).

Accounts of booming dunes, which incidently are visually and mineralogically indistinguishable from silent dunes, have been woven into the legends of eastern desert regions for over 2000 years and are mentioned in British scientific articles as early as 1812 (7). Figure (1) is one product of the first quantitative recording (location-Sand Mountain, 15 miles east of Fallon, Nevada) of f>20Hz booming (2). This particular amplitude trace (left side) was evoked by simply pullings one's hand slowly down hill through the sand. General conclusions drawn from several different tests are : (1) narrow single and multiple peaks are easily generated between 50 and 80 Hz (note the corresponding power spectral density trace (Δf=1Hz) on the right of figure 1); (2) mechanical to seismic conversion efficiencies the order of 1% to 5% are achievable; (3) the output can be modulated by different forcing profiles but the basic frequency range is not changed; (4) significant output does occur for f<20Hz; and (5) there is no readily perceptible difference between the transient vibrations produced by shaking a quantity of booming sand in a bottle which is initially at atmospheric pressure (760 torr) and then evacuated to 1.5 torr just as theory predicts (8).

Other features of thermal moonquakes are consistent with the booming process and the very small slumping volumes implied. Thermal moonquakes have a narrow frequency distribution as do booming dunes. Some thermal moonquakes display an evolving sequence during the lunar day which is very faithfully repeated from one day to the next. Purely by way of illustration, it has been suggested that the soil of the complicated slumping pattern, which could extend over a wavelength or so, is restored each lunar night to its preslumped condition (9). In the booming process local slopes would control the spectral outputs of each event and the very slight displacements required of each event in the sequence would permit the slumping of each element to continue over many cycles before significant local slope changes occurred. The roles of grain surface morphology, grain composition, grain shape, total Q, and the presence of an atmosphere are under investigation. The booming process, once understood,

THERMAL MOONQUAKES

Criswell, D. R. & Lindsay, J. F.

through a systematic laboratory and field program may provide a diagnostic technique for studies of grain adhesion, size distributions, slumping rates, and surface seismic properties over kilometer sized areas on the moon and Mars as well as on the earth.

References

1. Duennebier, F.K. (1972) Moonquakes and meteroids: results from the Apollo passive seismic experiment-short period data, dissertation Un. Hawaii.
2. Criswell, D.R., Lindsay, J.F. and Reasoner, D.L. (1973) Acoustic and seismic emissions of a booming dune, EOS, 54, #11, p. 1133.
3. Criswell, D.R. and Lindsay, J.F. (1973) Lunar landslides and booming dunes, EOS, 54, #4, p. 360.
4. Latham, G.V., Ewing, M., Press, F., Sutton, G., Dorman, J., Nakamura, Y., Toksoz, N., Lammlein, D., and Duennebier, F. (1972) Passive seismic experiment, Apollo-16 Preliminary Science Report (NASA SP-315) p. 9-1 through 9-29.
5. Kovach, R. L., Watkins, J.S., and Talwani, P. (1972) Active seismic experiment, Apollo-16 Preliminary Science Report (NASA SP-315), p. 10-1 through 10-14.
6. Husain, L., Schaeffer, O.A., Funkhouser, J., and Sutter, J. (1972) The ages of lunar material from Fra Mauro, Hadley Rille, and Spur Crater, Proc. Third Lunar Science Conf., Geochim. et Cosmochim. Acta Suppl. 3, vol. 3, pp. 1557-1567, M. I. T. Press.
7. Curzon, Marquess-Kedleston (1923) "Tales of Travel" p. 261-339, Hodder and Stoughton.
8. Bagnold, R.A. (1966) The shearing and dilatation of dry sand and the 'singing' mechanism, Proc. Royal Society, 295, part A, pp. 219-232.
9. Duennebier, F.K. and Sutton, G.H. (1973) Thermal moonquakes and small meteoroid impacts (presentation), Lunar Geophysics Conference, Lunar Science Institute, January.

figure 1