**WITHIN-NEST HYPOCENTER DISTRIBUTION AND WAVEFORM POLARIZATION OF DEEP MOONQUAKES AND THEIR POSSIBLE IMPLICATIONS.** Y. Nakamura, Institute for Geophysics, John A. and Katherine G. Jackson School of Geosciences, University of Texas at Austin, 10100 Burnet Rd., Bldg. 196, Austin, TX 78758-4445, U.S.A. (yosio@ig.utexas.edu).

**Introduction:** Deep moonquakes, discovered during the Apollo landing missions in the late 1960s to early 1970s, occur in isolated nests at depths about halfway to the center of the Moon. In spite of some previous efforts [e.g., 1, 2, 3], however, what causes them and what they tell us about the deep interior of the Moon remain as open questions.

The distribution of individual hypocenters within nests and their mechanisms may provide clues that help us find answers. Our earlier analysis, limited to using visually identified events and with the paltry computer power available to us at the time, indicated that individual hypocenters in the most active nest $A_1$ were confined within a radius of about 1 km and their polarities and amplitudes suggested slip directions that rotated as tidal stress changed [4].

The database has since been expanded several times by inclusion of many computer-matched events [5,6], and computers fully capable of handling the required computations of many more deep moonquake nests are now available. Thus, we have reanalyzed the $A_1$ hypocenters and expanded the analysis to include several other nests to see if our earlier results are still valid.

**Method:** The basis for computing relative hypocenter locations in a nest is a highly precise estimation of relative arrival times for both P and S waves for all possible pairs of events belonging to the nest. This estimation was done by cross-correlating the waveforms of pairs of events; the frequency derivative of the cross-phase spectrum of a pair of waveforms gives the time offset between the pair and its zero-frequency intercept gives the relative polarity of the waveforms. Relative hypocenter locations are then computed from relative P- and S-wave arrival-time differences at individual stations and relative S-wave arrival-time differences between stations.

**Re-examination of nest $A_1$:** A re-examination of nest $A_1$ using the expanded list of events essentially confirmed our earlier findings in spite of nearly 70% increase in the number of events including many whose waveforms are correlated at significantly lesser degrees. The hypocenters are mostly confined within 1-km radius and their vertical extent is slightly smaller than their horizontal extent, suggesting a near-horizontal, planer distribution. Furthermore, events of inverted polarity are slightly offset to the southwest from those of normal polarity.

**Other nests:** Not all nests contain individual events strong enough to allow cross-spectral analysis for relative arrival-time determination at sufficient accuracy. For this reason, of the remaining 315 currently identified nests, we first selected the following 26 nests: $A_6$, $A_7$, $A_8$, $A_9$, $A_{10}$, $A_{13}$, $A_{15}$, $A_{16}$, $A_{17}$, $A_{18}$, $A_{19}$, $A_{20}$, $A_{21}$, $A_{22}$, $A_{25}$, $A_{26}$, $A_{30}$, $A_{33}$, $A_{34}$, $A_{36}$, $A_{37}$, $A_{42}$, $A_{44}$, $A_{97}$, $A_{234}$ and $A_{257}$. The selection was based mainly on the number of events belonging to each nest. These 26 nests together with nest $A_1$ represent 2318 individual events, or about 35% of the 6549 events listed as being positively identified as deep moonquakes in our most recent event catalog (available on-line at ftp.ig.utexas.edu/pub/PSE/catsrepts, file name levetnt.0704). For each nest, we computed the relative arrival times of both P- and S-wave arrivals as before whenever the individual signals were sufficiently strong. The results for all 26 nests were quite similar to those for nest $A_1$; the relative arrival-time differences are all relatively small, consistent with a hypothesis that hypocenters in each nest are confined to a region of radius 1 km or smaller.

Nests usable for relative hypocenter determinations are further restricted by additional requirements for the number and combination of arrival-time differences. Thus we were able to compute relative hypocenter locations only for the following 12 nests: $A_6$, $A_7$, $A_{16}$, $A_{17}$, $A_{18}$, $A_{20}$, $A_{22}$, $A_{25}$, $A_{30}$, $A_{37}$, $A_{42}$, and $A_{44}$. As with nest $A_1$, the results for all these nests show a tightly confined distribution. The seemingly planer distribution observed for nest $A_1$ is not observed for any of the other nests. Two of the twelve nests, $A_{20}$ and $A_{25}$, contain hypocenters of clearly different polarities, but their locations are not displaced as with nest $A_1$.

**Waveform polarization:** For those nests in which events of opposite polarities are observed, events of opposite polarities are clearly separated in their occurrence times, as they occur over limited ranges of both anomalistic and draconic phases. However, at different nests, the times and phases when they occur are distinct. At nests $A_{20}$ and $A_{25}$, events of opposite polarities occur nearly, but not exactly, a half month apart. At nest $A_1$, the pattern of occurrence times of events of different polarities is entirely different and quite unique, with the occurrence of events of inverted polarity strongly influenced by the synodic phase, i.e., by the sun's position, in addition to the range limitation in anomalistic and draconic phases. At this nest, events of mixed polarities, i.e., normal at some stations but inverted at other stations, are also observed, suggesting again rotation of slip direction at the source.

**Discussion:** One might ask if the observed very limited spatial extend of hypocenters in each nest is an artifact of failing to include events that are spatially far apart in the analysis. However, we must reject this possibility because no positive correlation is observed between the arrival-time differences and the values of cross-correlation coefficients. Thus, the observed range of waveform cross-correlation is not attributed to differences in spatial separation of hypocenters but must be caused by something else, most likely a variation in source mechanism (slip direction) from one event to another.

One important observation is that deep moonquake nests are spread out over half of the Moon's front side, leaving ample space between them. This certainly is different from the distribution of earthquake hypocenters, most of which occur along extended linear faults. Any possible mechanism for deep moonquakes must account for this observation.

Another important observation is that in some nests there are events of opposite polarities, and also some with mixed polarity, suggesting that slip direction may vary with changing tidal stress inside the Moon. This is difficult to explain if deep moonquakes are caused by release of accumulated tectonic strain inside the Moon triggered by tidal stress changes. Tidal stress must play a leading roll in generating these quakes. How exactly the tides affect the generation of deep moonquakes, however, is a question that must be answered with future studies based on observations such as those shown here as examples.

**Conclusions:** Thirteen representative deep moonquake nests we examined all have highly restricted spatial distributions, being confined to regions with a spatial extent of 2 km or less in diameter. This is significantly different from the vast majority of earthquakes we observe on Earth. Some, but not all, nests clearly possess events having opposite waveform polarities to one another, suggesting that the slip direction at the hypocenter reverses with changing tidal stress. These and other specific characteristics of deep moonquakes must be taken in consideration in determining the real cause of these quakes.

**Acknowledgements:** Stimulating discussions I had with many of my colleagues throughout this study, in particular, Cliff Frohlich of UTIG, are greatly appreciated. This material is based upon work initially supported by the NASA under Grant No. NNG04GG62G issued through the Office of Space Science.

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