A NEW MOONQUAKE CATALOG FROM APOLLO 17 GEOPHONE DATA. J.-L. Dimech[1], B. Knapmeyer-Endrun[2], and R. C. Weber[1]. [1]NASA Marshall Space Flight Center, Huntsville AL 35805, USA (j.dimech@nasa.gov); [2]Max Planck Institute for Solar System Research, Göttingen, Germany.

Introduction: The Apollo 17 mission deployed the Lunar Seismic Profiling Experiment (LPSE), whose primary objective was to constrain the near-surface velocity structure adjacent to the landing site using explosive and impact shockwave sources detected by a a 100 m-wide triangular geophone array. However, it is not often appreciated that these geophones also operated in "listening mode" for continuous periods of time, ranging from just a few days up to 8 months-long between 1973 and 1977. Since the listening mode data were of no use to the profiling experiment, they have largely been ignored in subsequent analysis efforts. Only two preliminary studies have looked for seismic events in the listening mode data [1,2], and their analysis is based on just 26 days of data collected between July 1973 and December 1974. These studies reveal that the Apollo 17 geophones contain a rich collection of thermal moonquake waveforms, and might also contain information on local meteorite impacts (Yosio Nakamura, personal communication). However, most Apollo 17 geophone data has not yet been used to detect lunar moonquake events, and this includes a nearly continuous 8-month period from August 1976 to April 1977 (data available from JAXA).

In this study, further analysis of this 8-month period of data provides fresh insights into the number, characteristics, and temperal evolution of thermal moonquakes, and possibly meteorite impacts and other event types. This analysis has added value as the Apollo 17 landing site is close to significant topographic structures, such as the North and South Massif (with 2.2 and 2.3 km of relief respectively [3]), and the Lee-Lincoln scarp – the second-largest scarp on the Moon's surface – which is thought to be a seismically active thurst fault related to lunar cooling and contraction [4]. Apollo 17 geophones are well sited to detect signals from any of these features.

Preliminary inspection of the geophone dataset shows that hundreds of lunar seismic events are clearly visible during a 24-hour day (Fig. 1). Cataloging these events by hand would be a time-consuming and tedius process, and in the 1970's very expensive due to computing power requirements. However, computer technology and seismic techniques have advanced considerably in the last 40 years, and we now have novel ways to automatically generate earthquake catalogs and classify events in them quickly and objectively.

Moonquake detection and classification: In this study, we use an automated event-detection and classification technique based on 'Hidden Markov Models' to generate a seismic event catalog from LPSE listening mode data [5]. This technique has parallels with smartphone voice recognition software, and is able to detect seismic events in much the same way a smartphone can detect and classify spoken words. Preliminary inspection of the continuous dataset lead to the selection of three template events to be looked for in the continuous dataset (Fig. 2). The templates do not need to be matched perfectly in the continuous database, as the technique is able to account for variations in waveform shape and properties so long as the waveform has similar overall characteristics.

Event detections from Geophone 1: Currently, 2.5 months of an 8-month "listening mode" dataset has been processed, totaling 14,338 detections (Fig. 3a). Of these, 672 detections (classification 'n1') have a sharp onset with a steep risetime suggesting that they occur close to the recording geophone. These events almost all occur in association with lunar sunrise over a span of 1-2 days (Fig. 3b). One possibility is that these events originate from the nearby Apollo 17 lunar lander due to rapid heating at sunrise. A further 10,004 detections (classification 'd1') show strong diurnal periodicity, with detections increasing during the lunar day and reaching a peak at sunset (Fig. 3c). These detections probably represent thermal events from the lunar regolith immediately surrounding the Apollo landing site. The final 3662 detections (classification 'd2') refer to a template with emergent onsets and relatively long durations. These detections have peaks associated with lunar sunrise and sunset, but also sometimes have peaks at seemingly random times (Fig. 3d). Their source mechanism remains unclear. It's possible that many of these are misclassified d1/n1 type events, and further QC work needs to be undertaken. However, it is also possible that many of these events represent distant thermal moonquakes such as from the North and South Massif, or even the ridge adjacent to the Lee-Lincoln scarp. The anomalous event spikes (black arrows in Fig. 3d) will be the subject of closer inspection once the HMM catalog effort has been completed and refined.

References: [1] Cooper M. R. and Kovach R. L. (1975) *Proc. Lunar Sci. Conf. 6th*, p. 2863–2879. [2] Duennebier, F. (1976) *Proc. Lunar Sci. Conf. 7th*, p. 1073–1086. [3] Muehlberger, R. et al. (1973) Apollo 17 Preliminary Science Report, Ch. 6. [4] Banks M. E. et al. (2012) *JGR*, 117, E00H11. [5] Hammer, C. et al. (2012), *BSSA*, 102, 3, 948–960.

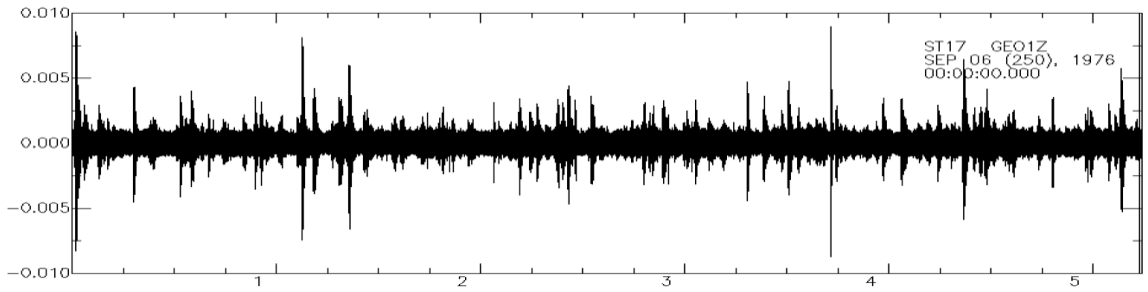

Figure 1. Fourteen hours of continuous data recorded by Apollo 17 Geophone 1, x axis is time, y axis is amplitude. The data have been filtered and despiked to remove transients and enhance the primary signal. At this scale, what appears to be a spike represents a single seismic event, such as a thermal moonquake. Hundreds of moonquake events are seen during a single day.

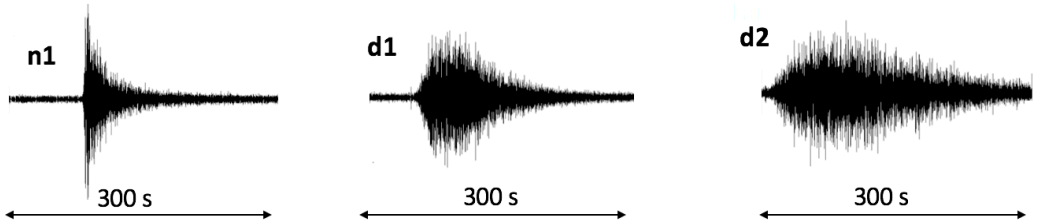

Figure 2. These event templates were extracted from the continuous database based on differences in appearance and properties. They are used to detect and classify other events in the continuous database with similar properties.

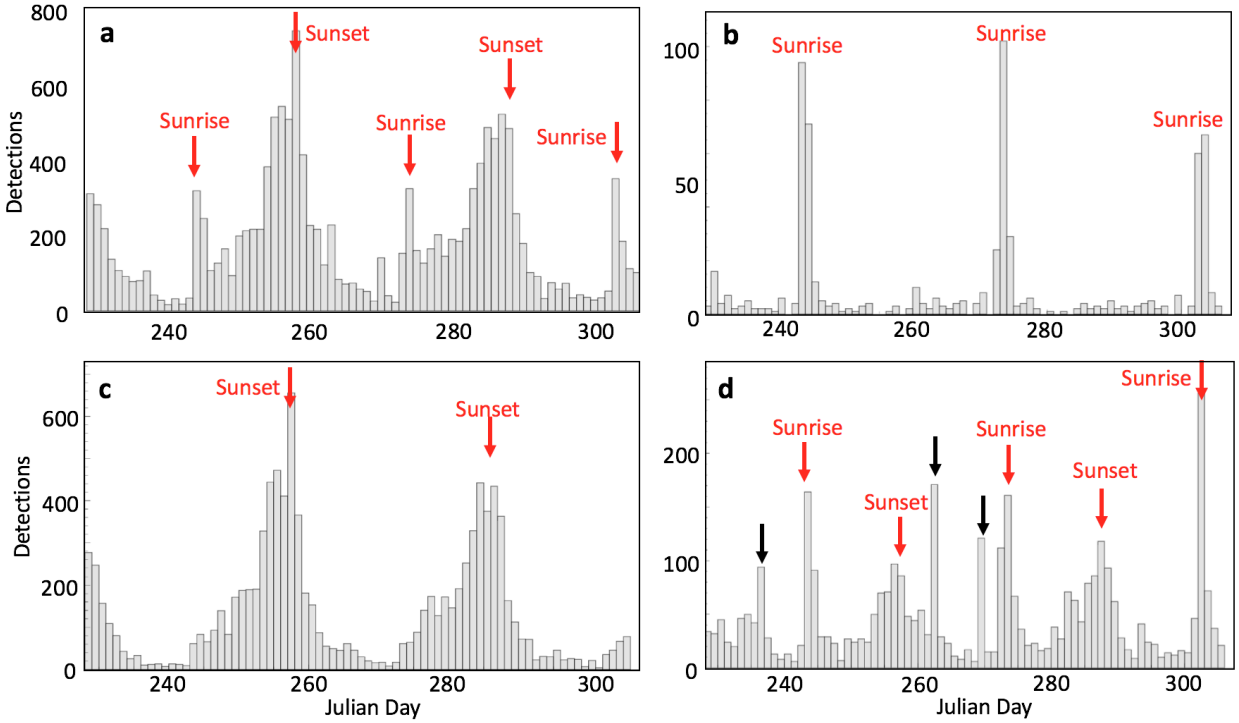

Figure 3. Histograms showing event detections per Julian day. They are broken down into four plots, showing (a) all event types; (b) event type 'n1'; (c) event type 'd1'; (d) event type 'd2'. Black arrows represent anomalous detections which are not associated with sunrise or sunset as referred to in the text.