SLIP DIRECTIONS IN THE A01 DEEP MOONQUAKE NEST. A. R. Turner and J. C. Hawthorne, University of Oxford (alice.turner@earth.ox.ac.uk)

Introduction: Deep moonquakes provide a unique insight into the stresses acting deep in the lunar interior. The periodicity of deep moonquakes suggests that the tidal stress affects their timing [1], [2]. However, the relative magnitudes of the tidal and tectonic stresses remain unclear. Do tides only trigger deep moonquakes by adding a small perturbation in stress on top of a large long-term tectonic stress? Or do the tides drive deep moonquakes, providing a stress that is much larger than a long-term tectonic stress?

To understand the relative magnitudes of the tidal and tectonic stresses, we use reversed polarity waveforms observed at the A01 nest. These events have highly similar waveforms, but with a reversed ground motion, suggesting an apparent reversal in the slip direction.

We consider two models for the reversed polarity waveforms (Figure 1). In the plug model the long-term tectonic stress is much larger than the oscillatory tidal stress. Thus, the shear stress at any location is always in the same direction. The apparent reversal of slip direction arises because slip occurs on two parallel shear zones either side of a moving "plug" (Figure 1a). In the time-dependent slip direction model, slip only occurs on a single shear zone, but the oscillatory stress is larger than the long-term stress, allowing the stress direction to change sign (Figure 1b).

To test these models, we note that in the time-dependent slip direction model, the stress cannot only change sign; it can also rotate in different directions [3]. Slip can occur in any combination of left,right, up and down, which could be fully described by two slip directions. In contrast, the plug model would only require a single slip direction to explain both the reversed and normal polarity events.

We seek to determine which model is more suitable to explain the reversed polarity waveforms, and thereby determine if a long term lunar tectonic stress is larger than a tidal stress, by identifying the number of slip directions among events in the A01 nest.

On Earth, the first step in characterising a region's stress state is studying the focal mechanisms; these are the first-order source characteristic of a seismic event described by the strike, dip and rake of the fault plane. However, lunar seismograms are unsuitable for traditional focal mechanism recovery methods. The lunar network has only four stations with a relatively small spacing, and moonquake signals are highly scattered. To overcome the highly scattered signals, we decompose the deep moonquake signals from the A01 nest into the slip directions (Figure 2).

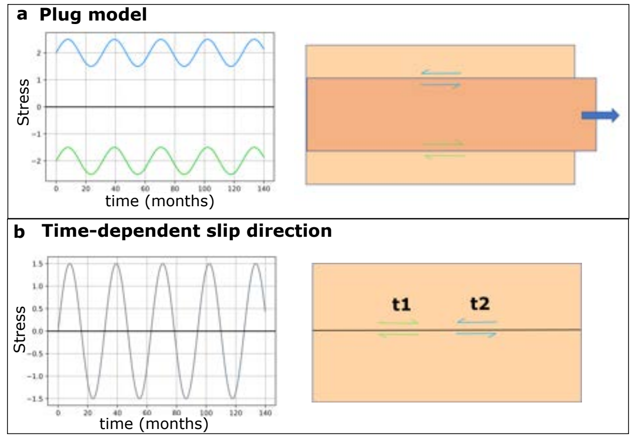

Figure 1: (a) The plug flow model. The long-term tectonic stress is much larger than the oscillatory tidal stress. The stress direction is constant. The reversed polarity waveforms arise because of parallel shear zones either side of a moving plug. (b) A tidally driven model where slip occurs on a single shear zone but the stress direction can change direction over time.

Method: We assume that all moonquakes in the A01 nest are occurring in the same location but may be slipping in different directions. We decompose the seismograms into the slip directions and the amount of slip in each of those directions for each moonquake (Figure 2). We use the principal component analysis (PCA) to carry out this decomposition.

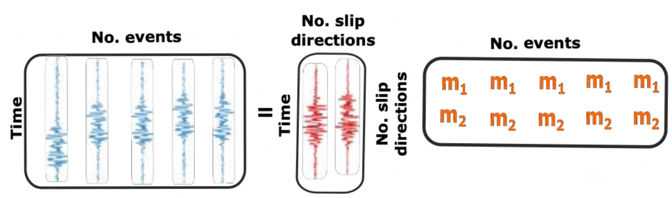

Figure 2: Illustration of the decomposition for the A01 slip directions of moonquakes carried out using the Principal component analysis. A matrix of seismograms from the A01 nest (blue) is decomposed into the slip directions (red) and the amount of slip in each direction for each moonquake (orange).

When analysing the decomposed slip directions, it is important to note that the PCA acts both on the moonquake signal, and the noise in the data. We compare the fraction of the total energy in each slip direction to the fraction that would occur by decomposing noise. The amount of energy in each slip direction expected by noise is calculated by randomly shifting the waveforms to create a large number of new datasets and recalculating the energy in each slip direction.

Preliminary results: Figure 3 show energy concentrated in each of the first three slip directions, calculated using data from the S12 station MHY component filtered between 0.25 - 1.75 Hz. The solid line shows the fraction of the energy in each of the slip directions, while the histogram shows the energy that could be expected from random noise. The energy in the first and second slip directions is larger than the energy from random noise, while the energy in the third slip direction could be from random noise. This suggests that there are two significant slip directions in the A01 nest.

The two slip directions in the A01 deep moonquake nest are more consistent with the model of a time-dependant slip direction. This could suggest that the main driving stress of deep moonquakes in the A01 nest is tidal, with only a small contribution from tectonic stresses.

Further slip direction analysis: Before we fully interpret our results, we must consider potential sources of error. There are several sources of error that may cause the PCA to assign energy from the first slip direction into a second, unphysical slip direction. Initial results suggest that the second component is real, however we are continuing analysis into the effect of poor waveform alignment, alignment of noise in the data or strong near surface scattering.

Once the significance is determined, we are particularly interested in looking at the amount of slip in each direction for each moonquake in the A01 nest, and therefore more confidently determine the slip directions of individual moonquakes. We will be able to track how the slip direction in the A01 nest changes over time and link them to the tidal phases to determine the relative magnitudes of the tidal and tectonic stresses.

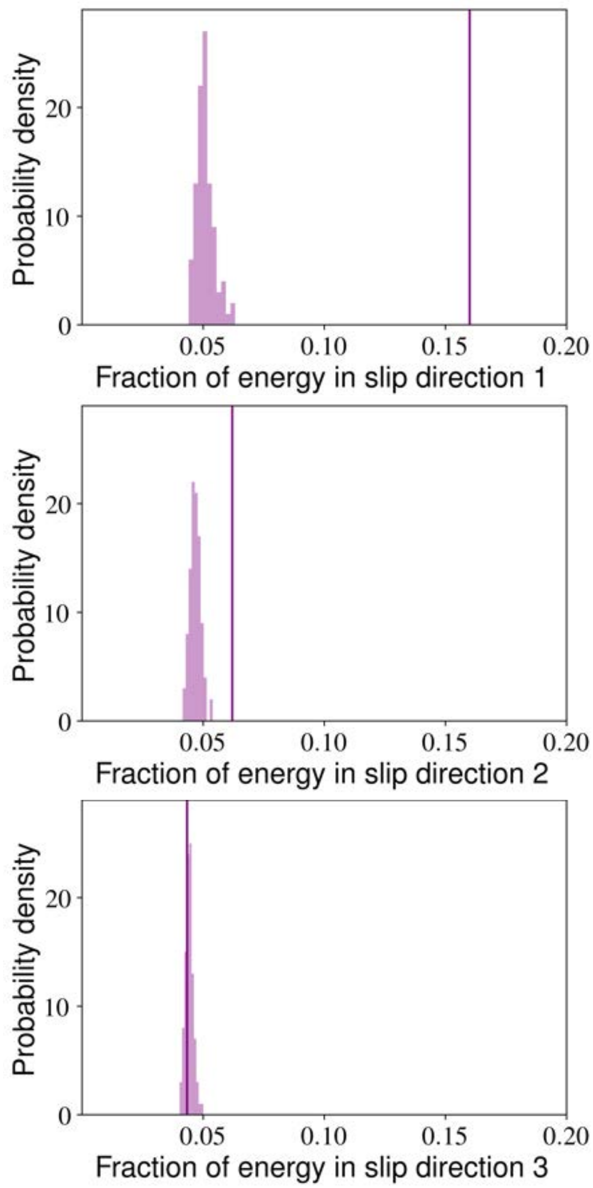

Figure 3: Solid vertical lines show the frication of energy that the A01 moonquakes have in each of the first three slip directions. We compare these lines to the histograms which show the energy that could be in each slip direction from random noise. The first two components have far more energy than you would expect from random noise. In particular, significance of the second component suggests that the slip direction rotates on the A01 moonquake fault.

References: [1] Goulty, N. R. (1979) Phys. Earth Planet. Inter, *19*(1), 52-58. [2] Minshull, T. A. and Goulty, N. R. (1988) Phys. Earth Planet. Inter *52*(1-2), 41-55. [3] Nakamura, Y. (1978) *LPS IX*