P'P' and PP precursor observations of the 660km seismic discontinuity

Elizabeth Day* & Arwen Deuss

EGU2010-9139 *ead33@cam.ac.uk Bullard Laboratories, Department of Earth Sciences, Cambridge, CB3 0EZ, UK

UNIVERSITY OF CAMBRIDGE

This poster participates in YSOPP — Young Scientists' Outstanding Poster Paper Contest

1. Introduction

What is P'P'?

P'P' (also known as PKPPKP or PKIKPPKIKP in the case of P'P'df) is a seismic phase which traverses the entire Earth, including the core, before reflecting off the Earth's surface (Fig. 1). Like PP and SS waves, the main P'P' arrival is preceded by smaller amplitude arrivals, known as precursors, which have been reflected at discontinuities below the Earth's surface (Fig. 2). P'P' precursors are referred to as P'dP', where d denotes the depth of the interface they have been reflected by.

As P'P' precursors have a relatively high frequency content (~1Hz) and approach discontinuities with a steep angle of incidence they are sensitive to sharp transitions and small scale structures.

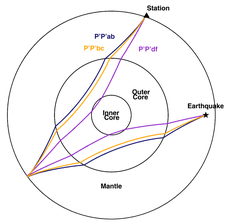


Figure 1: A cartoon showing the paths of the different P'P' branches.

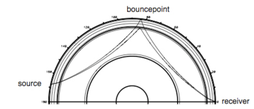


Figure 2: A cartoon showing PP precursors bouncing off mantle discontinuities and the main phase reflecting off the Earth's surface.

2. Methods

Stacking

PP and P'P' precursors are small amplitude phases which are not visible on individual seismograms. To allow the weak precursor signals to rise above the background noise level, traces are stacked in bins according to the bouncepoint of the precursor. Incoherent noise is suppressed, whilst the coherent signals of the main arrival and its precursors are enhanced. Phase weighted stacking (PWS) [1] is a non-linear stacking technique, which is used to identify the very small amplitude precursors.

Data selection and processing

- **P'P'** Broadband data, collected mainly by the Californian Seismic Networks and LASA array, have been stacked for a number of individual events (Table 1). Seismograms used in the stacks are filtered between 0.5 and 1.5 Hz (and 15 and 75s for the long period P'P') and normalized on the arrival of the main phase. They are then hand selected to ensure a good signal-to-noise ratio and clear precursor window. Synthetic seismograms are generated using the ray tracing program WKBJ [2].
- **Long period PP** Seismograms from a number of worldwide events are filtered between 15 and 75s, normalized and linearly stacked in bins of 20° diameter.

3. Regional variation of P660P and P'660P' observations

We frequently observe a clear P'660P' signal at short periods, regardless of tectonic setting (Table 1), as do other P'P' studies [5;6]. This has been interpreted as evidence for a sharp transition, over less than 2km [4]. We do not observe a strong P'660P' signal at long periods. The '660' is rarely detected by PP precursors at both long and short periods [3], with those studies that do observe it seeing a complex discontinuity with intermittent single and double reflectors [7]. The complexity of the '660' has been attributed to a variety of factors, most notably additional phase changes in non-olivine components of the mantle, such as garnet.

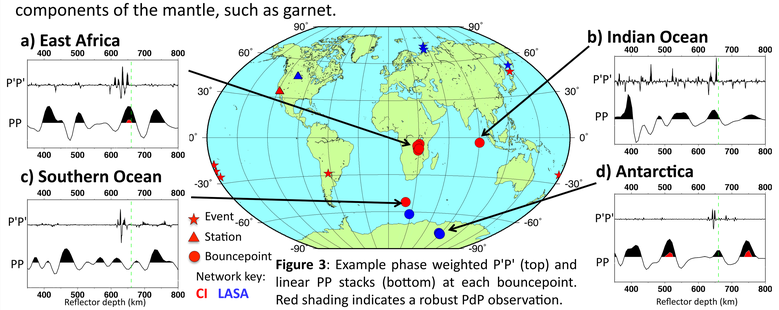


Figure 3: Example phase weighted P'P' (top) and linear PP stacks (bottom) at each bouncepoint. Red shading indicates a robust PdP observation.

Event	Depth (km)	Δ (°)	# Sta.	M_W	660 depth	Bounce Region
030994E	567.8	77.5	23	7.6	652	East Africa
081902A	630.9	81.2	80	7.6	645	East Africa
081902C	699.3	84.1	87	7.7	680	East Africa
071504C◆	577.2	77.7	35	7.1	660	East Africa
120907A	149.9	82.5	73	7.8	652	East Africa
060994A	647.1	67.0	9	8.6	-	Indian Ocean
042300B◆	607.9	81.1	26	6.9	658	Indian Ocean
111702C◆	479.8	69.1	87	7.3	642	Southern Ocean
083070	645	61.1	341	6.6˙	670	Southern Ocean
*102773◆	0	62	341	6.9˙	650	Antarctica
*110274	0	61.9	207	6.7˙	650	Antarctica
120973	0	59.6	342	6.8˙	655	Antarctica

Table 1: Analysed P'P' events (0.5-1.5 Hz) with observed precursors. Nuclear tests indicated by *. ◆ indicates event featured in Fig. 3. Body wave magnitudes are shown by ˙. Transition depths are calculated using the time difference between the P'660P' and P'P' arrival times. There are 15 events for which precursors are not observed. They tend to satisfy one or more of the following conditions; too small a magnitude, too shallow, too few stations or a noisy precursor window. Event 060994A has no 660 depth measured due to the exceptionally long source time function for this event.

4. 660km discontinuity topography under East Africa and frequency dependence

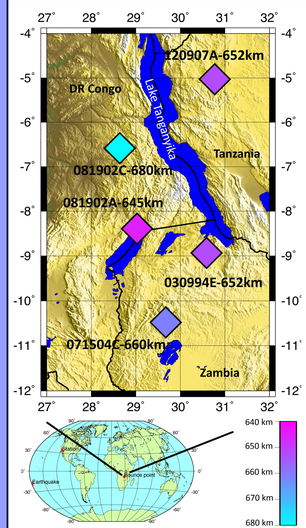


Figure 4: Variation in depth of the 660km seismic discontinuity in Eastern Africa. The depth is calculated from the absolute time difference between the short period P'P' and P'660P' arrivals using ak135 [8] as the reference model. There is up to 35 km variation in the depth of the 660 over 2°. This is comparable to the Fresnel zone of 0.5 – 1.5 Hz P'P'. 35km of apparent variation of 660 depth could also be caused by over 120km of variation in crustal thickness.

'660' topography from short period observations of P'P'

Short period P'660P' has a much smaller Fresnel zone than long period P660P and P'660P'. We detect up to 35 km of variation in the depth of the 660km reflector over a few hundred km (Fig. 3). This variation would prevent energy from 660km reflectors coherently stacking in long period, large Fresnel zone data types, making long period P'660P' and P660P difficult to observe, as illustrated in Fig.7. The shorter period P'660P' signal disappears at periods above 5.5s (Fig. 6), which is consistent with a Fresnel zone of 5° radius.

Additional deep reflectors

Long period P'P' reflects from an interface at around 720km depth (Fig. 3 and 6). This is likely to be related to the majorite garnet to perovskite phase transition.

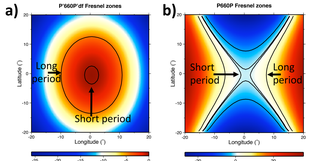


Figure 5: The different Fresnel zones for a) P'660P' and b) P660P at short and long periods (T=1s and 18s respectively).

- **Short period P'P'- 2nd order PWS**
- **Long period P'P'- 4th order PWS**

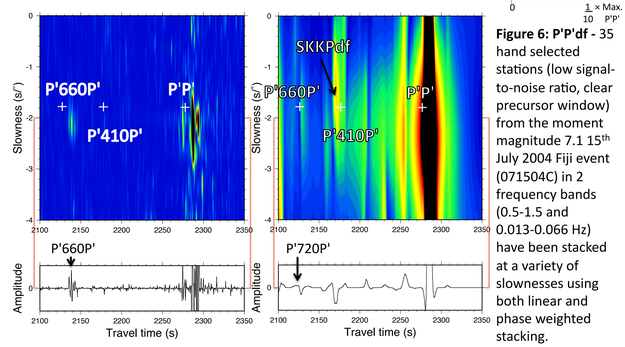
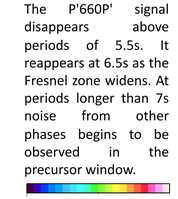
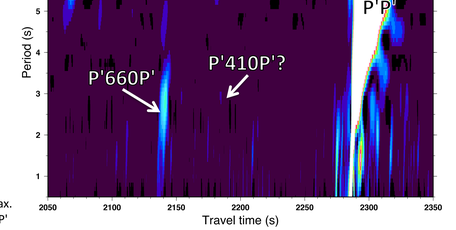


Figure 6: P'P'df - 35 hand selected stations (low signal-to-noise ratio, clear precursor window) from the moment magnitude 7.1 15th July 2004 Fiji event (071504C) in 2 frequency bands (0.5-1.5 and 0.013-0.066 Hz) have been stacked at a variety of slownesses using both linear and phase weighted stacking.

Figure 7: Phase weighted envelope stacks in 1s wide filter bands, normalized on P'P', for event 071504C. (p=-1.8s/°). The P'660P' signal disappears above periods of 5.5s. It reappears at 6.5s as the Fresnel zone widens. At periods longer than 7s noise from other phases begins to be observed in the precursor window.



- **Frequency dependence of P'660P' observations**



5. Conclusions

- P'660P' reflections are observed under East Africa, the Southern Ocean, Antarctica and the Indian Ocean.
- Short period P'660P' observations in East Africa detect substantial variation in 660km discontinuity depth; this would prevent coherent long period PP and P'P' precursor observations of the 660km discontinuity, due to the large Fresnel zones of long period data.
- Long period P'720P' signals are observed under East Africa. They are likely to correspond to a reflection from the majorite garnet to perovskite phase transition.

References: 1) M. Schimmel and H. Paulssen. Noise reduction and the detection of weak, coherent signals through phase weighted stacks. Geophys. J. Int., 130:497-505, 199
2) C. H. Chapman. A new method for computing synthetic seismograms, Geophys. J. R. Astr. Soc. 5481-518, 1978
3) S. Rost and M. Weber. The upper mantle transition zone discontinuities in the Pacific as determined by short-period array data. EPSL 204:347-361, 2002
4) F. Xu, J. E. Vidale and P. S. Earle. Survey of precursors to P'P': Fine structure of mantle discontinuities, J. Geophys. Res. 108:2024-2033, 2003
5) Y. Le Stunff, C. W. Wicks, and B. Romanowicz. P'P' precursors under Africa: Evidence for mid-mantle reflectors. Science, 207:74-77, 1995
6) F. Xu, J. E. Vidale and P. S. Earle. Mantle discontinuities under Southern Africa from precursors to P'P'df. Geophys. Res. Lett., 25:571-574, 1998
7) A. Deuss, S. A. T. Redfern, K. Chambers and J. H. Woodhouse. The nature of the 660km discontinuity in the Earth's mantle from global seismic observations of PP precursors. Science, 311:198-201, 2006
8) Kennett B.L.N., E. R. Engdahl and R. Buland. Constraints on seismic velocities in the earth from travel times Geophys. J. Int, 122, 108-124,1995

Acknowledgements: Data has been obtained from IRIS, the Southern Californian Earthquake Data Center and Paul Earle (LASA data via ftp://aslftp.cr.usgs.gov/pub/LASA). Elizabeth Day is funded by a NERC studentship (NE/F007175/1) and a CASE grant provided by Exxon-Mobil.
The authors thank Tim Craig and James Jackson for helpful discussion regarding African crustal thickness.