An Example of Imaging Deeper using Extended Vibroseis Cross-Correlation

Ross D. Costelloe*
Geoscience Australia
GPO Box 378 Canberra ACT 2601
Ross.costelloe@ga.gov.au

SUMMARY

Geoscience Australia has been collecting Vibroseis deep crustal reflection seismic data since 1999. Since 2013, Geoscience Australia has also collected the uncorrelated single sweep data for each VP of each survey. For a typical survey using three 12 s sweeps, each with 20 s listening time, this means collecting 96 s + 20 s = 116 s of data per VP, instead of 20 s of data per VP. This is nearly a 6-fold increase in data volume, and has been made possible by the availability of high capacity USB data disks. Using extended cross-correlation on the uncorrelated record data, it is possible to image deeper into the earth than using standard vibroseis cross-correlation. Geoscience Australia applied the method of truncated cross-correlation to a deep crustal reflection seismic survey collected over the Yathong Trough section of the Darling Basin in central NSW in 2013. This area showed unusual reflectivity below the Moho in the mantle, stimulating this study. The extended correlation stack showed some faint reflectivity visible from 18s to 24 s which may link to a region of higher reflectivity visible at about 18s in the mantle. Also, the truncated extended cross-correlation method appeared to show improved reflectivity in the mid to lower crustal areas.

Key words: vibroseis, cross-correlation, seismic, reflection

INTRODUCTION

Geoscience Australia has been collecting deep crustal reflection seismic data across regions of interest in Australia since the 1950s. Until 1997, all such reflection data were collected using explosive energy sources. Geoscience Australia has collected raw uncorrelated vibroseis shot records, together with stacked cross-correlated shots, in deep crustal seismic surveys since 2013. For all previous vibroseis surveys, from 1999, Geoscience Australia recorded only stacked, cross correlated shot records. Recording uncorrelated sweeps enables pre-processing of the uncorrelated records prior to creating a stacked correlated record for each VP. One such pre-process is extended cross-correlation. Extended cross-correlation has been used previously on deep crustal vibroseis data to investigate deep crustal and mantle reflections (Malinkowski and Brettwood, 2013, Okaya and Jarchow, 1989). Such deep reflections have been observed for example on the DRUM line north of Scotland where Flannan's Fault is imaged dipping well into the mantle (Blundell,1990, Reston,1993). Extended vibroseis cross-correlation can be used effectively when using upsweeps starting at low frequencies and sweeping to higher frequencies (Okaya and Jarchow 1989). The truncated extended cross-correlation technique involves cross-correlating with a truncated reference sweep starting at the normal low frequency of the full sweep and truncating at a lower final frequency than the full sweep.

Geoscience Australia, in collaboration with the Geological Survey of NSW, collected deep crustal seismic data across the Yathong Trough section of the Darling Basin in western New South Wales in July and December 2013. Line 13GA-YT2, Figure 1, from this survey was used for this investigation. A previous deep crustal survey in the northern part of the Darling Basin, the Thomson-Lachlan survey, imaged a strongly reflective flat Moho in the southern (Lachlan Orogen) area of the survey (Glen et.al. 2013). The Rankins Springs Deep Crustal Survey described by Jones (2009), which intersects this present survey (line 13GA-YT1), imaged a complex structure at the base of the crust with dipping and disrupted "Moho" reflectivity from 10 to 12 s Two Way Time (TWT) and patches of isolated reflectivity to 20 s TWT. The more northern line of the Rankins Springs survey showed a diffuse Moho at about 13 s (Jones, 2009).

The study line 13GA-YT2 shows a strong reflective band at 10 to 11 s, which may correspond to the Moho reflector package imaged in the other surveys. There is, however more strong reflectivity within the mantle between 16 and 18 s. For most areas of the continents that have been studied with deep crustal reflection seismic, the mantle is quite non-reflective. The band of reflectivity appearing on this line, and on other lines in this area of NSW, stimulated the application of extended cross-correlation, in an attempt to image possible deeper reflectivity in the mantle in this area.

METHOD AND RESULTS

The 2D deep reflection seismic line 13GA-YT2 used vibroseis as the energy source with 12 s sweeps and 20 s listening time, resulting in 20 s correlated shot records. The recording parameters are summarised in Table 1. For this study, truncated 6 s reference sweeps were created from the recorded reference sweeps by truncating to 6 s and applying the same 200 ms cosine taper to the end of the sweeps as was used on the full reference sweeps. The Yathong Trough survey was collected using three sweeps per VP, the frequencies shown in Table 1. During acquisition, the single sweep records were individually cross-correlated with their respective reference sweep, and the cross-correlated records stacked together, resulting in a single 20 s record for each VP. The cross-correlation and stacking of the data was done in the recording instruments, as is the standard practice. The length of the output records is the uncorrelated record length (32 s) minus the sweep length (12 s), i.e. 20 s, as in normal cross-correlation. Extended cross-correlation was applied to the data after the completion of the survey acquisition. Figure 2 shows the sweeps used for truncated extended cross-correlation. In this case, with extended cross-correlation, the output records are 26 s, i.e. 32 s minus 6 s.

The individual uncorrelated sweeps (each of 32 s, 12 s sweep and 20 s listening) and the 20 s correlated records were all recorded to disk in the field recorder. So instead of collecting a single 20 s record for each VP, three 32 s uncorrelated records plus the usual 20 s correlated record were collected, an almost six-fold increase in data. This increase in data volume was accommodated by using high capacity USB disks to store the data during the survey in the field, and by archiving the data to 3592 tapes post survey by the acquisition contractor.

Number of channels	300
Geophone Array	Linear 12 over 40 m
Station Interval	40 m
Record Length (Listening Time)	20 s
Sample Rate	2 ms
Sweep Length	12 s
Sweep Frequencies	6-80 Hz
	12-120 Hz
	8-90 Hz
Vibrator Point (VP) Interval	80 m
Vibrator Array	3 Vibrators
	15 m pad to pad
	15 m moveup

Table 1. Recording parameters

Field stacks were produced, and Table 2 shows the processing sequence applied. On the field stack images produced for line 13GA-YT2, deep reflection features were apparent at about 18 s, as shown in Figure 3a. Subsequently, the uncorrelated shots were re-correlated using the truncated extended cross-correlation method to image deeper into the earth to investigate if there was reflectivity even deeper than that seen at 18 s. After extended correlation, the new 26 s shot records were processed through the same field stack sequence, except the pilot traces and spectral equalisation frequency ranges were reduced, Table 2. The extra 6 s deeper imaging into the mantle showed no deeper areas of significant reflectivity, although there were some hints of possible east dipping reflectivity linking to the deep package of sub-horizontal reflectivity at about 18 s and a possible area of sub-horizontal reflectivity at 25 s around station 4800.

- Standard cross correlation with pilot traces 6 – 120 Hz
- Truncated extended cross correlation with pilot traces 6 – 66 Hz
- Dummy straight line geometry definition (CDP interval 20 m, nominal fold 75)
- SEG-D to Disco format conversion, resample to 4 ms
- Inner trace edits
- Common midpoint sort
- Gain recovery (spherical divergence)
- Spectral equalisation over 8 to 108 Hz, (1000 ms AGC gate) standard correlated
- Spectral equalisation over 8 to 60 Hz, (1000 ms AGC gate) extended correlated
- Application of automatic residual statics
- Normal moveout (NMO) correction based on single regional velocity
- Band pass filter
- Common midpoint stack
- Signal coherency enhancement (digistack 0.65 and fkpower)
- Trace amplitude scaling for display

Table 2. Seismic reflection processing sequence for line 13GA–YT2

Figure 3 shows a stack of the extended correlation c) compared to the normal field stack a) for the section of line 13GA-YT2 highlighted red in Figure 1. The normal correlated data were also processed through the reduced bandwidth spectral equalisation that was applied to the extended cross-correlation data. The stack of this dataset is shown in Figure 3b. Between 18 s and 24 s, the extended correlation stack shows some faint reflection energy dipping to the east. This appears to be related to the strong sub-horizontal package of reflections visible just before 18 s to the west. In the shallow part of the section, the extended correlation stack has not effectively imaged the basin sediments. However, at deeper levels in the crust, the apparent reflectivity on the extended correlation stack is stronger than the conventional stack and reflective packages are better imaged and more continuous. This may be a result of cross-correlating with the reduced bandwidth reference sweep, as the higher frequencies above 60 Hz transmitted into the earth by the vibrators are not likely to be present in the reflected signal from mid crustal depths, owing to significant attenuation in the upper crust. The field stack using the reduced bandwidth spectral equalisation, Figure 3b, also shows the poor imaging of the sedimentary basin, but shows very little difference to the normal field stack, Figure 3a, in the deeper crustal section. This indicates that the improved mid to lower crustal reflectivity visible on the extended cross correlation stack, Figure 3c, is the result of the truncated cross-correlation process.

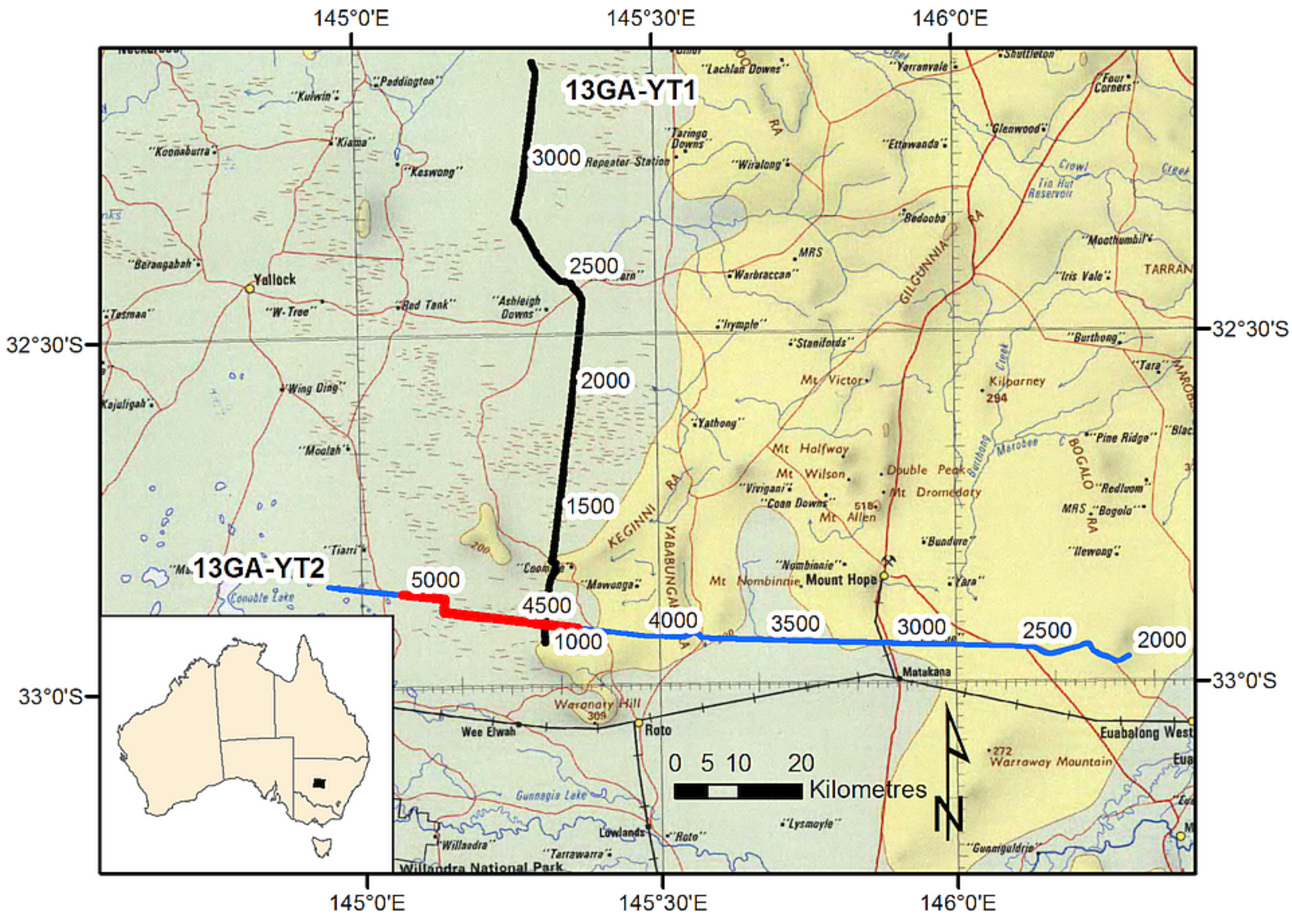

Figure 1. Location of the Yathong Trough Seismic survey with line 13GA-YT2 shown in blue, and station numbers annotated. The section of the line which is stacked in Figure 3 is coloured red.

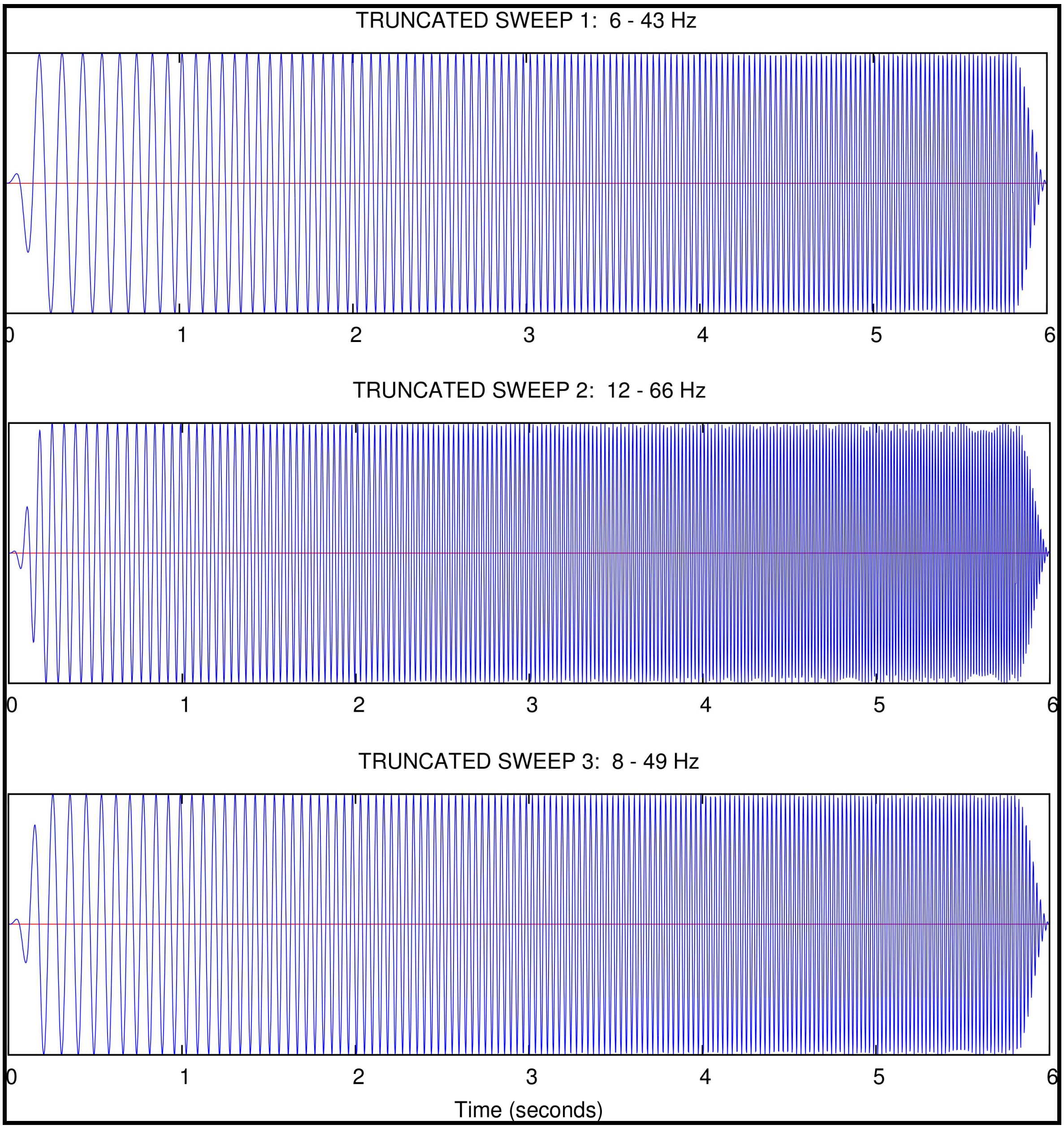

Figure 2. Truncated sweeps used for truncated extended correlation.

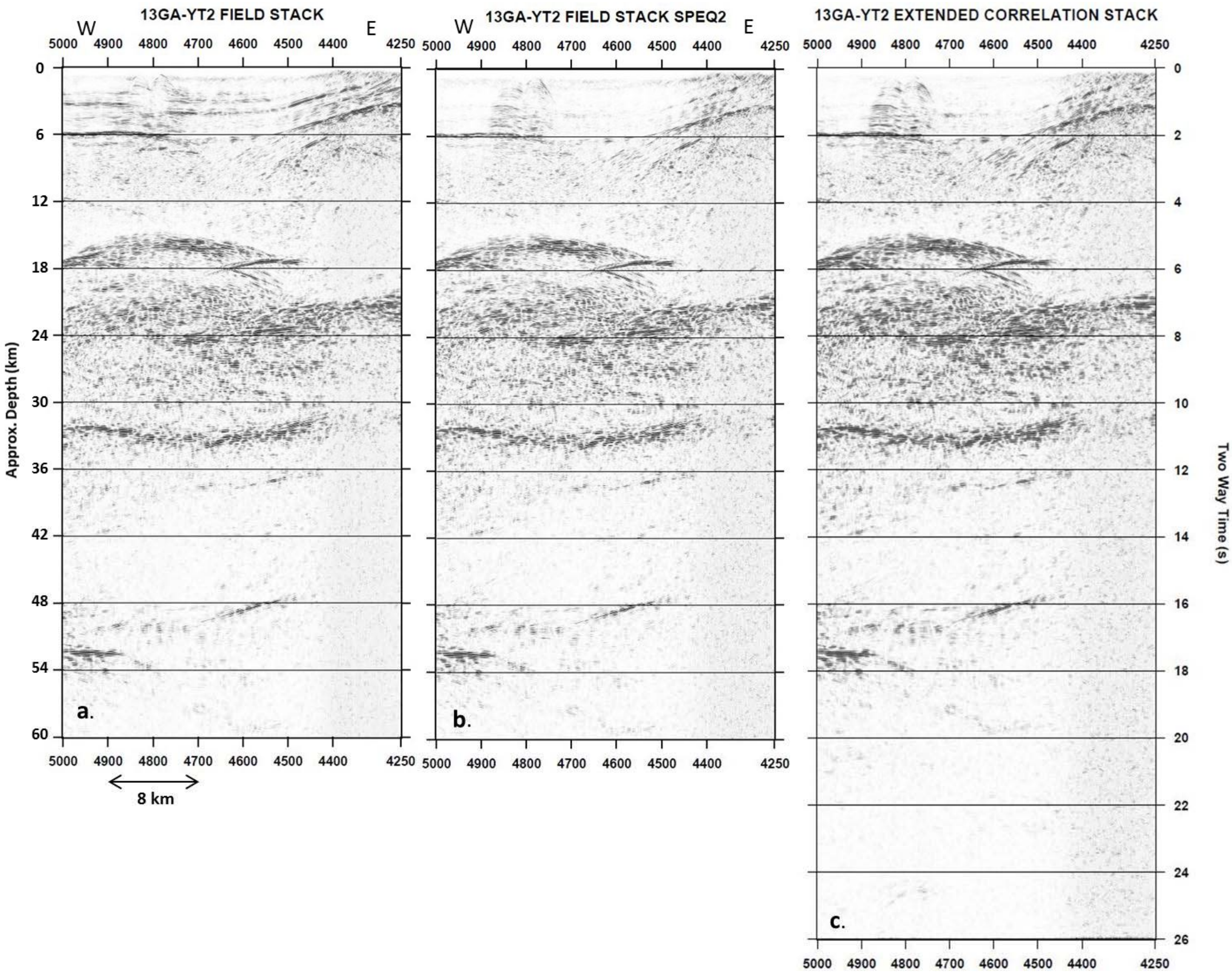

Figure 3. a) Field stack of 13GA-YT2 showing deep reflectivity at about 18 s TWT. Station numbers are annotated both at the top and at the bottom of the figure. b) Field stack using reduced bandwidth spectral equalisation, similar to c). c) Truncated extended cross-correlation stack of the same section of line 13GA-YT2, showing imaging of the crust and mantle to 26 s TWT. The vertical scale is equal to the horizontal scale with depths approximated assuming an average crustal velocity of 6 km s-1, so 1 s TWT is 3 km depth.

CONCLUSIONS

The extended cross correlation method applied to the Yathong Trough data in The Darling Basin has provided imaging to an extra 6 s (approximately 18 km) and some possible deeper reflectivity at reflection times of up to 2 s that may be related to strong reflective regions visible between 16 s and 18 s on the conventional cross-correlated stacked data, as well as some possible reflectivity at 25 s. The truncated extended correlation stack also showed improved signal energy and imaging in the mid to lower crust. This improvement in crustal reflectivity signal may be the result of using only the lower frequencies of the sweep in the cross-correlation process, which is valid for these times as the higher frequency components of the sweep are not returned from these depths in the crust. This may indicate that using truncated cross-correlation may be a way to both optimise deep crustal imaging, as well as imaging deeper into the mantle than conventional vibroseis cross-correlation.

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