

Acquisition and processing of the 2012 Albany–Fraser Orogen deep reflection seismic survey

by

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Introduction

Geoscience Australia (GA), in collaboration with the Geological Survey of Western Australia (GSWA) and the Tropicana Joint Venture, comprising AngloGold Ashanti Australia Ltd and the Independence Group NL, contracted Terrex Seismic to collect the Albany–Fraser Orogen seismic survey from 23 April to 5 June 2012. The survey consisted of four lines, 12GA-AF1, 12GA-AF2, 12GA-AF3 and 12GA-T1. The lines were located on local roads and along the Trans-Australian Railway access road. Figure 1 shows the location of the lines. The survey was designed as a transect across the Albany–Fraser zone in Western Australia and to image the relationship between the Yilgarn Craton to the west, the Albany–Fraser Orogen in the centre, and the Madura Province beneath the Eucla Basin to the east. A total of 671.9 km of deep crustal seismic data was collected.

Acquisition of the reflection seismic data

Logistics of the seismic survey

Acquisition of the reflection seismic data commenced on 23 April 2012 at the western end of line 12GA-AF2 (AF2). AF2 was completed on 2 May 2012 about 25 km northeast of Esperance covering 158.4 km. Line 12GA-AF1 (AF1) then commenced from the west on Fisheries Road, about 15 km northeast of Esperance. AF1 was collected up to the boundary with the Cape Arid National Park and was completed on 10 May 2012, covering 114.06 km. The crew then mobilized on 11 May 2012 to the western end of line 12GA-AF3 (AF3) about 130 km to the east of Kalgoorlie on the Trans-Australian Railway access road. Recording continued until 27 May 2012 when the line was finished near Haig. AF3 covered 319.12 km in total. Two

days of testing commenced and the camp was moved to the Tropicana site to the north. Acquisition of line 12GA-T1 (T1) commenced on 1 June 2012 from the north and was completed on 5 June 2012, covering a total of 80.32 km. The average production for the whole survey was about 17 km per day.

The data acquisition crew was accommodated in a mobile trailer camp which contained all accommodation, kitchen, dining, laundry, workshop and office facilities. The data acquisition proceeded with the crew operating along the verges of the shire roads for lines AF1 and AF2. The railway access road provided good access for the vibrators and crew vehicles and for the camp trailers for line AF3. T1 was located along a narrow track leading to the Plumridge Lakes Nature Reserve and some minor vegetation clearing had to be done to allow access to crew heavy vehicles. As the crew was operating along public roads, a traffic management firm was contracted to provide signage of traffic hazards and to manage seismic crew and public traffic around the back and front crews and the vibrators.

Recording parameters

Table 1 shows the recording parameters that were used for the acquisition of the Albany–Fraser Orogen seismic survey. The parameters were chosen based on previous deep seismic data collection experience and on sweep frequency parameter testing, which was completed before the start of the survey. A set of tests was designed for the Eucla Basin section of line AF3, and is described in a later section.

The seismic data were recorded using an active spread of 300 channels, spread over 12 km. SM24 10 Hz geophones were used in the receiver array, with 12 geophones per station. The 12 geophones were evenly spread over the 40 m station, with approximately 3.3 m between geophones, with arrays centred on the surveyed peg locations. The geophone array was designed to have some effect in attenuating surface wave noise (Pritchett, 1990), and to be easily deployed in the field. Each geophone string of 12 consisted of two sets of six series-connected geophones, the two strings connected in parallel.

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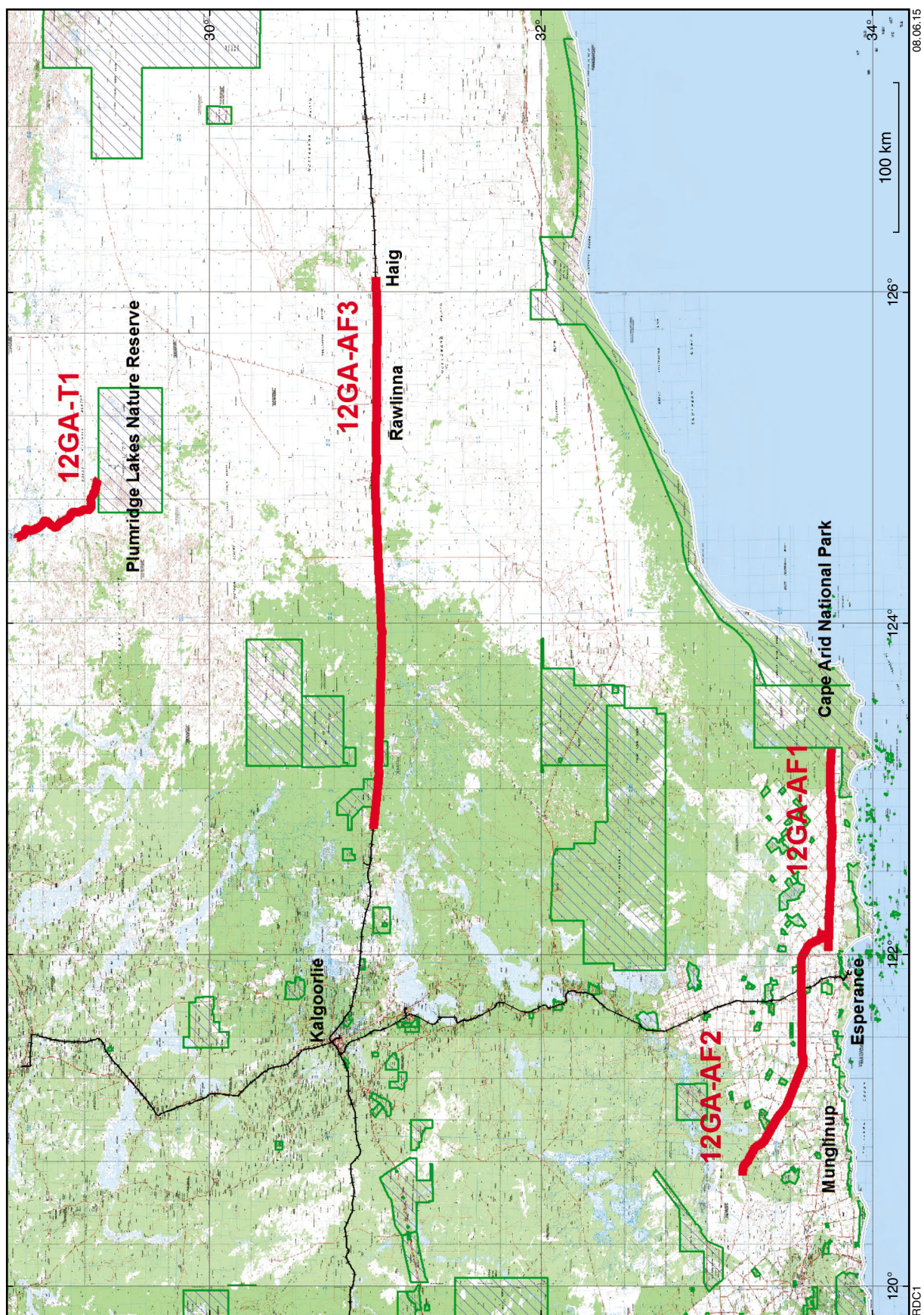


Figure 1. Location of the Albany–Fraser seismic lines

The source array, consisting of three AHV-IV Hemi-50 vibrators, was located at the centre of the 12 km spread, giving a maximum source-to-receiver offset of 6 km. The vibrators were spaced with the pads 15 m apart. The vibrators moved up 15 m between sweeps so that the trailing vibrators moved to the locations previously occupied by the vibrator in front of it. Three sweeps were recorded for each vibration point (VP), with each sweep individually cross-correlated with its reference sweep and all three cross-correlated records stacked together to produce the SEG-D shot record for each VP. Each sweep ranged over a different frequency range as shown in Table 1. The three sweeps together gave a weighted array covering 60 m per VP. The array helped to reduce source-generated surface wave noise in the in-line direction. VPs were spaced every second station, 80 m apart, and the centre of the vibrator array was located midway between survey stations.

Table 1. Data acquisition parameters

<i>Source</i>	3 IVI Hemi-50 vibrators
<i>Source array</i>	15 m pad to pad, 15 m moveup
<i>Sweep length</i>	3 x 12 s
<i>Sweep frequency</i>	6–64 Hz, 10–96 Hz, 8–80 Hz
<i>Vibration point (VP) interval</i>	80 m
<i>Receiver group</i>	12 geophones @ 3.3 m spacing
<i>Group interval</i>	40 m
<i>Number of recorded channels</i>	300
<i>Nominal fold</i>	75
<i>Recording instrument</i>	Sercel 428XL
<i>Record length</i>	20 s
<i>Sampling interval</i>	2 ms

Field QC and data management

The seismic data were recorded to disk in SEG-D demultiplexed format using a Sercel 428XL recording system, and then transferred each day to the on-site geophysicist via a USB memory stick. The data were recorded at 2 ms sampling rate with no low-cut filter and a 0.8 Nyquist frequency (200 Hz) high-cut filter. The sweeps were 12 s duration, with 20 s listening time, resulting in 20 s stacked correlated records. At the end of each day's recording, a laptop running Paradigm DISCO/Focus software on Red Hat Enterprise was used to run a processing sequence to view the shot data and create brute stacks for quality control of the data. At the end of each line, two identical LTO data tapes (A and B) were created containing all the SEG-D data for that line. Each SEG-D stacked correlated record was 11.5 MB in size, and total data volume of 93.8 GB was recorded for the survey.

Processing of the reflection seismic data

Hardware and software

The reflection seismic data were processed by the Onshore Seismic and Magnetotelluric Section of GA in Canberra. The data were initially processed using Paradigm DISCO/Focus software on a Red Hat Enterprise Linux Sun Fire X4600 M2 server, with the final processing steps and archiving of the data done on the replacement server for the X4600, an HP DL585 server running Paradigm Echos software on Red Hat Enterprise Linux.

Table 2. Final processing sequence

Crooked line geometry
SEG-D to DISCO format conversion
Inner trace edits
Notch filter
Common midpoint sort
Gain recovery
Spectral equalization
Floating datum residual refraction statics
Velocity analysis
Residual statics
NMO and stretch mute
Bandpass filter
Velocity analysis
Offset regularization and DMO
Common midpoint stack
Post-stack time migration
Coherency enhancement
Mean datum statics
Trace amplitude scaling

Processing overview

Standard deep crustal seismic processing procedures were used as summarized in Table 2 and briefly explained in the following sections.

Crooked-line geometry

This initial process defined the acquisition geometry of each line. The roads along which the survey was conducted were not straight, so crooked-line geometry was defined for each line. For this 2D survey, the bends in the lines can affect the resulting image. At sharp bends in the lines there is likely to be smearing and poor resolution of shallow data.

Also, deeper dipping structures may not image correctly, depending on the relative directions of the line and the dip of the structures. Line T1 had the most significant bends and so was most affected by these imaging issues.

SEG-D to DISCO format conversion

The field data were recorded in SEG-D Revision 1 format. The data were loaded into the processing system from the LTO tapes and converted into the internal DISCO format for processing.

Trace edits

The inner two traces nearest to the vibrators (trace 150 and 151) were omitted from the processing as the source array actually extended across them creating significant early time noise.

Notch filter

A 50 Hz notch filter was applied to selected traces of some shots on lines AF1 and AF2 where the data were significantly affected by powerline interference.

Common depth point sort

The shot data were sorted into common depth point (CDP) bins, which had been defined in the crooked-line geometry process. The CDP bins were defined at 20 m intervals based on the source-receiver midpoint locations. A line of best fit through those midpoints, called the CDP line, was generated and which differs from the surveyed station line. All traces from any shots which had source-receiver midpoints that fell within the predefined CDP location bins, were gathered into the same CDP bin along the previously defined crooked-line geometry.

Gain recovery

A time-variant gain was applied to the data to account for the spherical divergence of the seismic energy as it propagated from the source.

Spectral equalization

Spectral equalization was used to attenuate source generated and random noise, especially ground-roll, relative to the higher frequencies of the sweep signal.

Floating datum refraction statics

Refraction static corrections (time shifts) were applied to the traces to compensate for the time variations caused by varying topography and near-surface regolith thickness and velocity. These near-surface low velocity layers can

cause differing delays to the reflection signal which, if not corrected, can degrade the stack (Cox, 1999). Refraction statics were also applied to set the reference datum level of the seismic data to a specified elevation. For the lines in this survey, a datum of 400 m AHD was used, so zero time on the final data corresponds to 400 m AHD. Refraction statics were calculated based on picking first breaks on shot records, and the long wavelength average statics subtracted, to leave residual refraction statics on a floating datum, which at this stage of the processing left the data essentially surface referenced. The method of calculating the statics is based on the works of Taner et al. (1988).

Velocity analysis

First-pass velocity analyses were done at regular intervals along the lines, using coherency plots and/or constant velocity stacks.

Residual statics

Residual statics were calculated and applied. Residual statics make small adjustments to the refraction statics based on cross-correlating traces within CDP gathered in a selected time gate, to maximize the correlation to further improve the stack response.

Normal moveout and stretch mute

Normal moveout (NMO) corrections were applied based on the first-pass velocity analyses. NMO is required because each CDP gather contains traces with differing source to receiver offsets. Delays resulting from the differing offsets, and therefore differing raypaths of the seismic signal, are compensated for by the NMO correction. Muting of the early time (less than 1 s) data is required as the NMO process significantly stretches the far offset data.

Bandpass filter

A bandpass filter was applied to the data to remove noise outside the seismic sweep signal frequency band.

Offset regularization and dip moveout

Offset regularization and dip moveout (DMO) (Deregowski and Rocca, 1981) were applied to enable dipping and flat reflections to stack with the same NMO correction. DMO shifts reflections both within and between CDP gathers based on apparent dip of coherent events.

Velocity analysis

A second pass of velocity analysis was to pick appropriate velocity field to stack the DMO data.

NMO and stretch mute

NMO corrections were applied to the DMO corrected gathers based on the DMO velocity analyses.

Common midpoint stack

The stack process sums the NMO/DMO corrected data for each CDP gather at each time sample. The signal to random noise ratio is improved by the square root of the number of traces stacked (fold). The Albany–Fraser Orogen data were stacked to a nominal fold of 75 traces per CDP, giving a theoretical signal-to-noise ratio improvement of 8.7.

Post-stack time migration

Migration is the final imaging process and moves data to its correct spatial location based on dip. Dipping reflections visible on the stack move up dip and become steeper and shorter. Diffractions visible on the stack should collapse to a small region on the migration. Figure 2 displays a small section of line AF2, which shows high reflectivity in the upper crust. The upper panel is the stacked section and the lower panel is the migrated section. The display shows how migration has collapsed a large diffraction and has moved linear dipping reflections

from their pre-migration locations on the stack section to their true locations on the migrated section.

Time migration methods were applied to the stacked data using a smoothed velocity model derived from the stacking velocities. Two different algorithms were used: omega-x finite difference migration; and Kirchhoff migration. Both algorithms are described in Yilmaz (2001).

Coherency enhancement

Coherency enhancement was applied to enhance data satisfying continuity over several traces and within specified dip limits.

Mean datum statics

The average refraction statics were applied to the data, shifting it from surface reference to the datum of 400 m AHD.

Trace amplitude scaling

A final automatic gain control scaling was applied to the data for display to equalize the displayed amplitudes of the data.

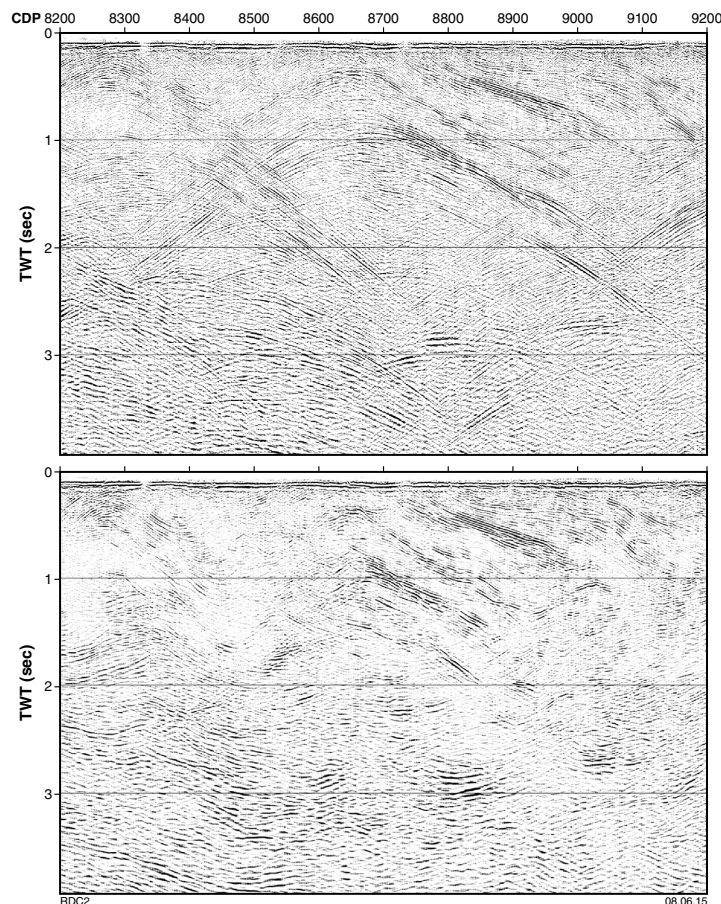


Figure 2. Stack (upper) and migration (lower) of a small section of line 12GA-AF2

Testing program

A review of previous surveys over the Eucla Basin was made during design of the survey, as the effectiveness of the standard source and recording parameters were unknown in the carbonate terrain of the Eucla Basin which would be encountered when recording line AF3. A testing program was designed, to be implemented on line AF3, once there was a noticeable degradation of data quality being collected using the standard parameters. Previous surveys over other areas of the Eucla Basin had resulted in poor imaging using the seismic method (Leven and Barton, 1991). As part of the testing program, 4.5 Hz geophone strings (enough for 150 channels of 12 per channel) were used to compare the data quality obtained with that obtained using the standard 10 Hz geophones. Increased bandwidth, especially in the low frequencies, was expected to improve the data interpretability where there was significant scattering of energy, as was expected in the karst limestone areas of the Eucla Basin. Previous seismic acquisition programs have been unable to record interpretable seismic data in areas of surface limestones (Wei and Hall, 2011). Data for line AF3 were recorded to the end of the planned line using the standard parameters, as the data quality remained acceptable. After production was completed on the line, some testing was done using the 4.5 Hz geophones in a parallel spread to the production spread, using various sweep parameters, as shown in Table 3.

The testing program included two basic changes to the normal acquisition parameters; a comparison of 4.5 Hz geophones to the 10 Hz geophones, and a comparison of low frequency, non-linear sweeps against higher frequency linear sweeps. Both changes were aimed at acquiring more low frequency signal in the data.

A parallel spread of 150 channels of 4.5 Hz geophones was laid on the southern side of the track being used as the seismic line, with the 10 Hz spread on the northern side, so that 150 channels of data with 10 Hz geophones and 150 channels of data with 4.5 Hz geophones were simultaneously recorded. Table 3 shows the acquisition parameters of the testing program that was conducted.

Table 3. Test sweep parameters

Test	VP range	Sweep type	Frequency range
1	10675.5 10910.5	Linear	3–48 Hz
			3–24 Hz
			3–16 Hz
2	10824.5 10848.5	Linear	3–64 Hz
			10–96 Hz
			8–80 Hz
3	10824.5 10844.5	Non-linear 9 dB/Oct	3–48 Hz
			3–24 Hz
			3–16 Hz
4	10824.5 10833.5	Non-linear 9 dB/Oct	3–64 Hz
			10–96 Hz
			8–80 Hz

The section of line common to all tests lies from station 10674 to station 10984, with a maximum of 10 fold. Each sweep was correlated and stored as a separate record. For the experimental VPs, the vibrators did not move up between sweeps but vibrated all three sweeps from the centre position of the array.

Results of the testing program

Generally, the linear sweeps show better data quality than the non-linear sweeps, and the 10 Hz geophones show a similar response to the 4.5 Hz geophones. The wider bandwidth sweeps (Table 3, tests 2 and 4) also show improved data quality compared to the lower frequency sweeps (Table 3, tests 1 and 3). The tests confirm what was observed during production on AF3, i.e. that the original acquisition parameters are effective in imaging through the limestones of the Eucla Basin in this area, and are as good as or better than the other tested parameters.

Data archiving

The final processed data were converted to SEG-Y format, with the SEG-Y trace headers loaded with correct metadata. The SEG-Y EBCDIC headers contain a summary of the acquisition and processing parameters used. Images of the final stack and migrated data were created from the final SEG-Y data at 1:100 000 scale for the full 20 s, and 1:50 000 scale for the top 8 s of data. The final processed data, metadata and images for this survey are available for download from the GA website at <www.ga.gov.au/minerals/projects/current-projects/seismic-acquisition-processing.html>.

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