Crustal architecture of the Capricorn Orogen, Western Australia and associated metallogeny

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SUPPLEMENTARY PAPER

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Seismic Reflection Data Processing
The following sequence was used to process seismic reflection data for lines 10GA–CP1, 10GA–CP2, and 10GA–CP3:

- SEG-D to Disco format conversion, resample to 4 ms
- Quality control displays
- Crooked line geometry definition (CDP interval 20 m)
- Inner trace edits
- Common midpoint sort
- Gain recovery (spherical divergence)
- Spectral equalisation (1000 ms AGC gate)
- Application of floating datum residual refraction statics
- Application of automatic residual statics
- Velocity analysis
- Normal moveout
- Band pass filter
- Offset regularisation and dip moveout (DMO) correction
- Velocity analysis
- Common midpoint stack
- Migration
- Signal coherency enhancement (digistack and fkpower)
- Application of mean datum statics, datum 200 m (AHD), replacement velocity 5900 m/s
- Trace amplitude scaling for display

A simplified processing stream was used in the field to produce field stacks to control and monitor data quality whilst the survey was in progress. As the transect was close to linear, with just some changes of geometry, it was processed using algorithms based on an assumption of 2D geometry. This 2D assumption has implications for the processing and interpretation of the resulting processed data; these consequences are explained in the description of the key processing steps (see below).

As the seismic survey followed the available access routes, none of the three segments were straight. 10GA–CP1 had marked changes in direction, and the northern end of 10GA–CP2 also had sharp bends around topographic ridges. Therefore, the processing was based around the definition of a section line (Common Depth Point, or CDP, line), which smooths out variations in the line (see below).

Variations in surface elevation, weathering layer depth, and weathering layer velocity can produce significant time delays in land reflection data. Variations over distances shorter than the spread length can degrade the stack, with the reflections no longer aligning across the traces to be stacked. Variations over distances longer than a
spread length will not significantly affect the stack quality, but can introduce spurious long wavelength structures in the stacked reflections; static corrections are applied in the processing stream to remove these effects. For the Capricorn reflection seismic processing, static corrections were calculated by picking first-break refracted arrivals from shot records, and then creating a near-surface refractor model of the weathering layer. The refraction static corrections were applied in two stages using a floating datum. An intermediate step of automatic residual static corrections produced fine tuning of the corrections. The final static corrections were calculated relative to a datum of 200 m (AHD), using a replacement velocity of 5900 m/s. Details on the picking of the first breaks and other processes related to common depth point calculations are detailed below.

Migration is the final processing step, and involves moving dipping reflections to their most likely lateral positions based on an assumed velocity distribution. Reflections that appear to be dipping on the stack section will be moved up-dip and shortened after migration. Diffraction hyperbolas resulting from discontinuities, such as the termination of reflectors at faults, and which are visible on the stack section, should collapse into a small region after migration. If migrated correctly, the final time section should have dipping reflectors in the correct spatial location, under the 2-D assumption. Note that areas with poor signal-to-noise ratios, and those with sharp bends in the line, can produce artefacts in the data that will not migrate successfully. The appropriate migration parameters are determined by trials on suitable dip ranges and migration velocities. Commonly the migration velocity function is taken as a fraction of the stacking velocities; 70-85% of the stacking velocities were used for the Capricorn data. For lines CP-1 and CP-2 migration was implemented with a frequency-space algorithm (Yilmaz 2001), which represents a finite-difference approximation to the monochromatic wave equation. For line CP-3 a time–space Kirchhoff migration algorithm (Stolt & Benson 1986) was employed.

There are a number of significant steps in the course of processing the reflection data that have an imprint on the character of the final record sections.

Common Depth Point Modelling

The data was binned into common midpoint gathers based on a calculated CDP line, and then processed using the CDP method. The CDP line is a curve of best fit through the midpoints between sources and receivers, which optimises the fold of the data and minimises the subsurface area of reflections contributing to each nominal CDP. Each trace (source–receiver pair) is allocated to the CDP bin nearest to its midpoint. The CDP bins were defined to be 20 m along the line. The effects of bin size, and of midpoint scatter within the bin, are most critical at shallow depths. Where the line has sharp bends, there is likely to be smearing and poor resolution of shallow data. The effect of bends on deeper data can also be significant, depending on the relative directions of the seismic line, and the dip of the structures to be imaged.

The CDP line was processed as if it was straight, ignoring the effects of changing azimuth along the line. This simplification of the processing to 2D geometry, applied at the start of the processing sequence, is reasonable for large sections of the line that are relatively straight. The 2-D assumption does not hold through significant bends in the line, and in such regions it is not possible to achieve migration of reflectors into their correct spatial locations.
Picking First Breaks

The onset of the seismic energy has to be determined for each receiver for every vibrator location. This process of picking first breaks for each shot is time consuming. Although automatic methods of picking are used, each set of first breaks needs to be checked and these frequently require editing. Also, the quality of the first-break waveforms depends on the nature of the geology, both at the source and at the receiver arrays. In some parts of the line, a significant proportion of the first break picks were discarded due to poor signal-to-noise ratios. The number of picks for each shot in the model can vary along the lines, and as a result, the number of layers to be modelled must be specifically selected. Once the first breaks for the line have been picked and edited and the number of layers to be modelled is selected, the refractor model can be calculated. A one or two layer model can usually provide a suitable solution to the effects of weathering. For the Capricorn line, a single layer model was selected to best represent weathering over the entire transect.

Spectral equalisation

Spectral equalisation is a process used to sharpen the reflection wavelet and to suppress low-frequency energy, primarily ground-roll energy, which is surface wave energy generated by the vibrators. The frequency spectrum of the data is flattened over a specified frequency range and within a specified time gate, thereby reducing the high energy, low frequency surface-wave noise relative to the higher frequency energy of the reflections. Therefore, the resulting data has better resolution, particularly in the shallow part of the section (0–2 s two-way travel time (TWT)). The selection of an appropriate frequency range and time gate is based on selective testing and on spectral analysis of the data.

Normal moveout correction

The normal moveout (NMO) correction removes time variations across CDP gathers, by adjusting for time delays caused by progressively increasing offset between source and receivers. The NMO correction is applied as a stacking velocity that best aligns the reflections in the CDP gather. Two different techniques were used to calculate the stacking velocities: velocity scans and constant velocity stacks. Both techniques result in a velocity field varying in time and space (along the line), which maximises the stack response of the data. Velocity analysis requires interactive selection of optimal stack responses, and is one of the most time consuming processes in the processing sequence. Velocity analysis is usually made on spectral equalised CDP gathers after automatic residual statics, and also after dip moveout corrections are applied. Analyses can also be iterated where required, and areas of complex geology or poor stacking quality may require more closely spaced velocity analyses. Velocity boxes annotated on the seismic sections are the final velocities picked from the dip moveout gathers, with all corrections applied except for the mean refraction statics; that is, the velocities are applied prior to moving the data to its final datum.

Dip moveout correction

The dip moveout (DMO) correction, also known as partial pre-stack migration, adjusts the NMO correction based on the increase in stacking velocity encountered as the structural dip increases, and has the effect of correcting the NMO to account for different dips occurring along the line, based on the 2-D assumption. The process
effectively moves reflection energy between traces within and between CDP gathers based on the apparent dip of the reflectors, creating a new set of DMO-corrected CDP gathers. After DMO, intersecting dipping and flat reflections will correctly stack with the same stacking velocity. DMO is a computationally intensive processing step.

**Common midpoint stack**

The common midpoint stack is simply the summing of traces in a CDP gather to produce a single trace at the CDP location. The traces in the gather are aligned by the NMO and DMO processes, with the aim of an optimal sum. In principle, stacking the data can improve the signal-to-noise ratio of the data by \( \sqrt{n} \), where \( n \) is the number of traces summed (the fold). A nominal fold of 75 resulted from the acquisition geometry for the Capricorn seismic survey.

**REFERENCES**
