SEISMIC REFRACTION ANALYSIS OF SEDIMENT FILL IN CYCLONE GRABEN, NEEDLES DISTRICT, CANYONLANDS NATIONAL PARK

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INTRODUCTION

The young system of grabens that lies east of Cataract Canyon in the Needles district of Canyonlands National Park provides an excellent area for studying graben formation and for measuring fault scaling relations. This has been done in the past (Cartwright et al., 1995) and excellent exposure has aided in making measurements of fault length and displacement. Sediment fill in the floors of these grabens has generally been estimated at 15 m or less, though a geophysical study in the Devil's Lane graben suggested as much as 90 m of sediment (Grosfils et al., 2003).

We have carried out seismic refraction and gravity surveys in Cyclone graben, which is slightly larger than Devil's Lane, to investigate if all these grabens have such significant sediment fill. If these canyons typically hold 90 m or more of sediment fill, extension fault scaling relationships (between length and displacement) would need to be adjusted.

To analyze our seismic refraction data, a simple time-term inversion method has most commonly been employed (cf. Abrahamson, Michaels, Trenton, this volume). To check the robustness of this technique for modeling the floor of Cyclone graben, I have compared results obtained using the reciprocal (delay-time) method to the time-term inversion for one of our refraction lines, as well as performed tomographic inversions of that data.

METHODS

Data Acquisition

We carried out a detailed gravity survey along the axis of Cyclone graben, and a series of shorter seismic refraction lines distributed along the length of the graben. We used both 36-channel and 48-channel spreads of 10 Hz geophones with 10 m spacing. We used a 38 kg accelerated weight drop as an energy source. Shots were taken at the endpoints, as well as every third geophone.

The seismic data were collected in the field with a pair of Geometrics GEODE 24-channel seismographs and a GETAC ruggedized laptop running SGOS software. Noise was kept to a minimum by real-time monitoring of the signal. The shots were stacked 9 to 16 times at each shot-point and, for the most part, energy was reaching across the full spread.

Seismic Data Analysis

First breaks were picked and travel-time diagrams were created (figure 1) using the Pickwin module of the SeisImager program from Geometrics. To invert the data, there were three methods available: a time-term inversion method, a reciprocal (delay-time) method, and a tomographic method. The time term inversion is the quickest and easiest, but provides a very basic vertically layered velocity model. The reciprocal and tomographic methods require much more input and adjustment, and provide a significantly more detailed velocity model. In our survey, we had six seismic refraction spreads, and if the time-term inversion provides an accurate enough model, further time spent on reciprocal and tomographic methods would be redundant.

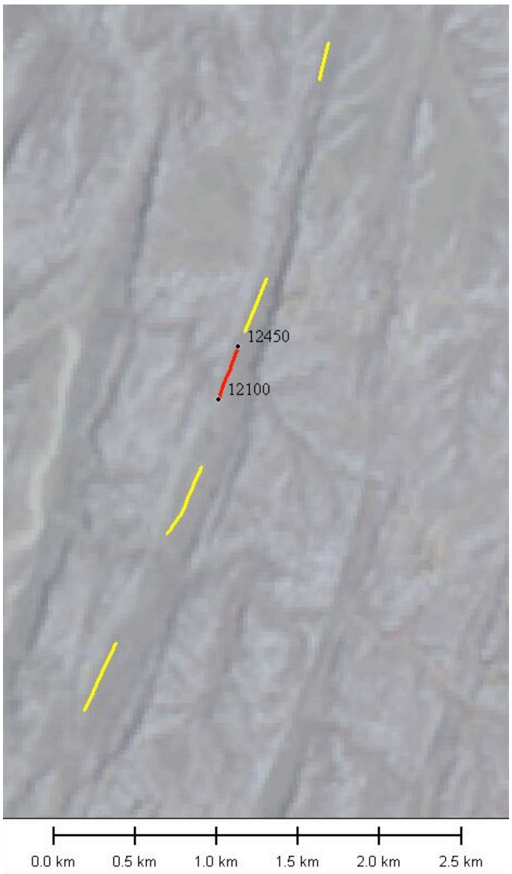

Figure 1: Location of line 12100-12450 (red) with respect to other refraction lines (yellow).

The time-term method is a quick and easy way to estimate refractor depth. This method only requires layer assignments for each of the first break arrivals. The time-term method is based on a few simplifying assumptions, which may be valid in our case; it assumes discrete constant velocity layers as well as a horizontal refractor. For our data, I assumed a two layer model, although the addition of a shallow low velocity layer could be added.

The reciprocal method provides a more detailed subsurface structure, and can interpret lateral velocity contrasts. As implemented in the SeisImager software, the reciprocal method is similar to the delay-time method described by Burger (1992). Delay times are calculated under each geophone from shots on either side of the geophone for which reciprocal travel times are available. In order to effectively utilize the reciprocal method on a spread, significant overlap of refracted arrivals is needed in the travel-time data. The spreads in our survey did not contain significant overlap, so this method is useful only in the centers of each spread. I used the same travel time curves and choice of second layer arrivals for the reciprocal method as for the time-term inversion.

Utilizing refraction tomography in this study is possible due to the large number of shot-points per line. The tomographic method requires the input of an initial velocity model, as well as instructions on how to iterate. If the tomographic inversion is robust, then the process should converge to a similar result for many different initial models. The easiest initial model to use is that generated by the time-term inversion method. Convergence of the results of tomographic inversion to a model similar to that produced by the time-term method would help confirm the validity of the time-term method for our data.

I analyzed one of our seismic refraction lines with all three methods. The line chosen lies near the middle of Cyclone graben and extends from our survey point 12100 to 12450 (Fig. 1). This is a 48-channel line (470 m long) and was chosen because it had the cleanest seismic data. While all three methods were applied, I focused on testing the limits of the tomographic method. The reciprocal method was used for completeness, but there is very little overlap in this spread (Fig. 2).

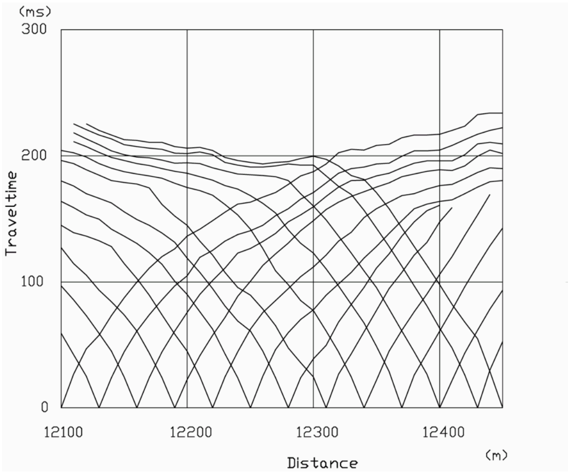

Figure 2: Travel time curves for spread 12100-12450

RESULTS

The time-term inversion method produces a model with approximately 50 m depth to the bedrock refractor on this spread (Fig. 3a). The matrix inversion error is less than 2 ms.

Over the region of applicability, the reciprocal method matched the time-term data within 10%, yielding a depth closer to 45m. Only the four outermost shots were useful in producing the model, and the effective overlap was only a third of the spread length (Fig. 3b)

The tomographic method, as mentioned previously, requires the input of a starting velocity model. In theory, regardless of the initial model, the process should converge to a similar final model. The velocity model produced by the time-term method (Fig. 3a) was used as a starting model producing the model shown in figure 3c.

To investigate the stability of the tomographic method, simple two-layer velocity models with bedrock depths of 10, 20, 30, 40, 60, and 100 m were used as initial models and the resulting inversions compared (Fig. 4). Each inversion was run with 30 iterations and each converged to a velocity model very similar to the result of inversion that used the time-term result as the initial model, with bedrock depths of approximately 45 m.

In addition to confirming the depths found in the time-term inversion, the tomography model revealed slightly higher bedrock velocities at the southern end of the spread than at the northern end. A shallow low velocity layer is also generated by the tomographic inversions. This is expected and corresponds to the upper most wind blown sediments, but the fact that it is generated by the tomographic inversion without being present in the initial model emphasizes the strength of this method.

DISCUSSION

For our study, the time-term method provides a sufficient model for most purposes. It yields the approximate depth to bedrock and any significant variation of that depth along a seismic spread.

The reciprocal method is difficult to use with our data as the bedrock refractor is deep with respect to the length of the spread. The reciprocal method gives a slightly improved model of the middle of the spread that generally agrees with the results of the time-term inversion.

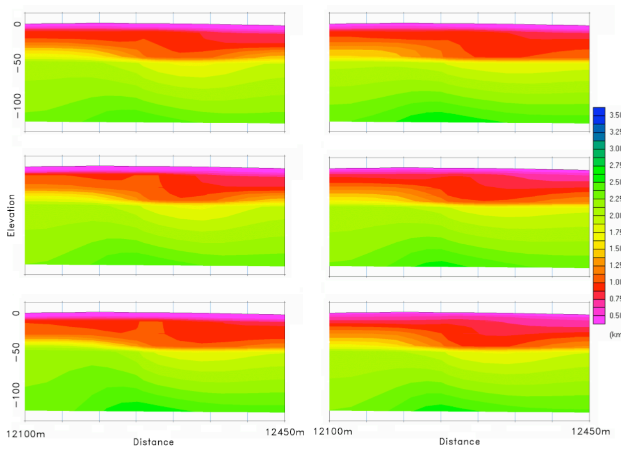

Figure 4: Tomography results for different initial conditions. Left column: 10m, 20m, 30m depth. Right column: 40m, 60m, 100m depth.

Refraction tomography performed in this area also confirms the results of the time term inversion, and better constrains the velocities of the sediments and bedrock. It does not necessarily affect the interpretations of fault displacement, but provides an interesting look at possible paleodrainages and shallow low velocity layers.

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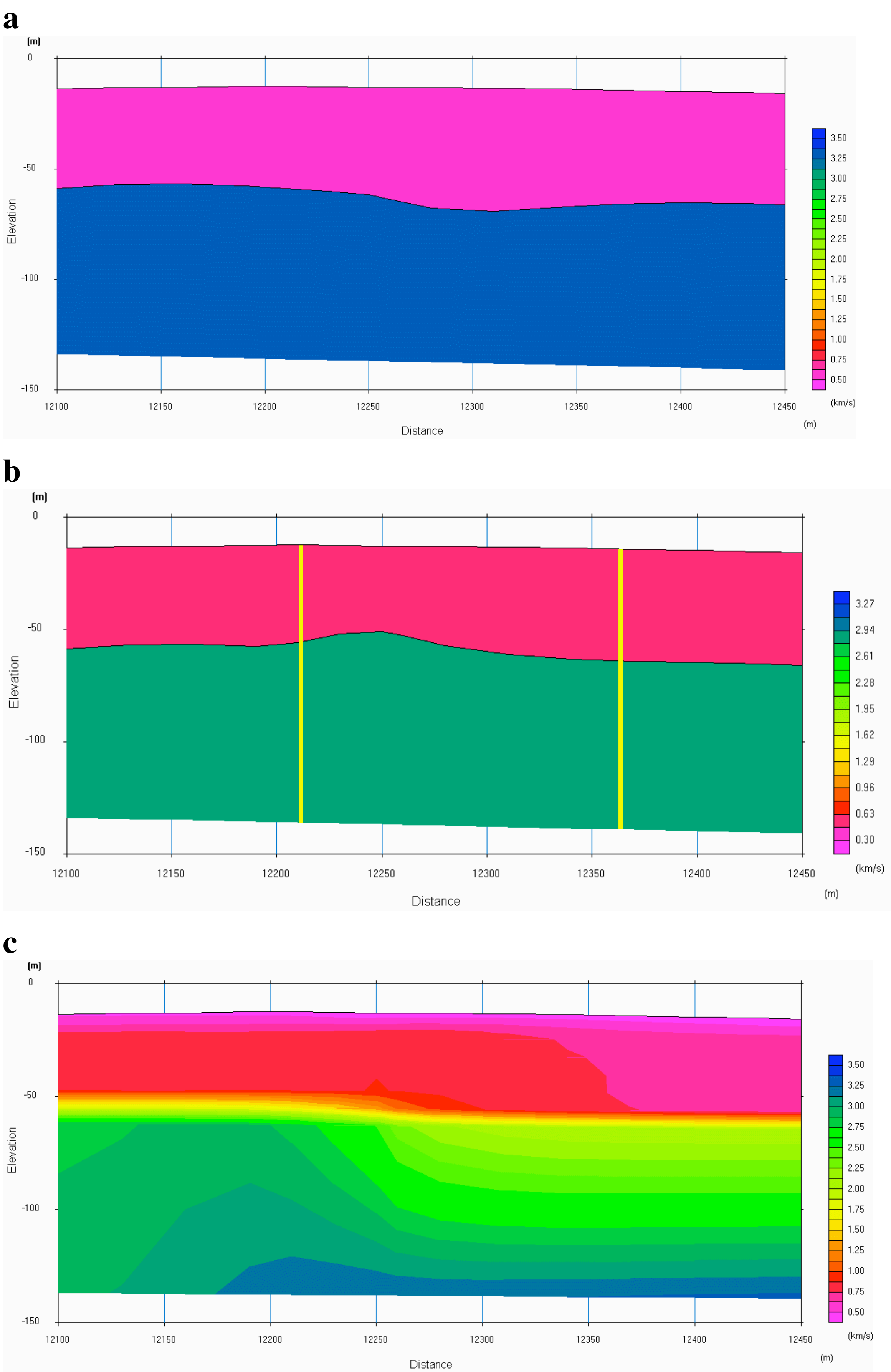

Figure 3: Comparison of time-term method (a), reciprocal method (b), and tomographic inversion (c) for the seismic refraction line spanning survey points 12100-12450. Yellow lines indicate overlap area for the reciprocal method. Elevations are relative survey point 10000 at the southern-most end of Cyclone graben.