SEISMIC AND GRAVITY ANALYSES OF CYCLONE GRABEN, CANYONLANDS NATIONAL PARK, UTAH

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INTRODUCTION

Cyclone Graben, which is approximately 4.5 km long, is located in the Needles District of Canyonlands National Park in southeastern Utah, and is part of a kilometer-scale extensional fault system. The graben floors in Canyonlands are covered by a layer of sediment, which obscures the bedrock. Previous estimates of the thickness of this sediment include 3 m to 7 m (Cartwright et al., 1995) and 0 m to 10 m (Cartwright and Mansfield, 1998). However, recent geophysical surveys of nearby Devils Lane graben have revealed sediment thicknesses of over 90 m on the floor of the graben, indicating that previous estimates of fault displacements may be four to ten times too low (Grosfils et al., 2003). If sediment thicknesses in Cyclone Graben are shown to be higher than previous estimates, such thicknesses might be expected throughout the entire area. Thus fault displacement estimates throughout the region, which are often based only on exposed topography, and other calculations based on displacement such as extensional strain rates, are likely to be incorrect. Therefore, in order to characterize the geometry of the subsurface beneath the floor of Cyclone Graben, seismic and gravity data were collected and analyzed.

METHODS

Field Methods

Our research team ran six P-wave seismic refraction lines, ranging in length from 240 m to 480 m, axially down the length of Cyclone Graben. In each case, 10-Hz vertical geophones spaced at 10 m intervals were connected to a Geometrics G24 Geode. The seismic source for all but one (for which a sledgehammer was used) of the seismic refraction lines was a PEG 40 accelerated weight drop with a 38 kg weight. Shots were taken at the beginning and end of each line, and at set intervals down the length of the line.

Relative gravity was measured with a Lacoste & Romberg Model G gravimeter with Aliod 100 nulling with a 0.001 mGal precision. Gravity measurements were recorded at a total of 49 stations located approximately 100 m apart running axially down the length of Cyclone Graben. Researchers attempted to take the readings from the middle of the width of the graben and returned to a base station approximately once every hour or less in order to be able to correct for drift effects.

Data Analysis Methods

Seismic first breaks were picked in PickWin95 and travel time data were then analyzed using both RefractSolve (by modeling dipping homogenous layers) and PlotRefa (by time-term inversion). First breaks at geophones close to the shot point often indicated the existence of a low-velocity layer at the surface, so three layer models were assumed with both modeling programs – the shallowest layer representing a thin layer of unconsolidated sediment near the surface, the second layer representing the main body of sediment on the floor of the graben, and the third layer representing bedrock.

Gravity data were corrected for instrumental drift, latitude, elevation (free air and Bouguer), and surrounding terrain. Terrain corrections were conducted with a Hammer (1939) chart. After corrections were completed, individual gravity loops were strung together and linearly detrended to correct for instrument and tidal drift. A range of subsurface models was then assessed with GravModel.

RESULTS AND DISCUSSION

Figure 1 shows the results of analyses for 5 of the 6 P-wave seismic lines. The sixth seismic line was omitted because it was further from the center of the graben than the rest of the lines, and thus the depth-to-bedrock values for this line were likely deceptively low. Only the average depth of each line is shown because the accuracy of the exact topography produced by the modeling programs is questionable due to error in picking first breaks and layer assignments.

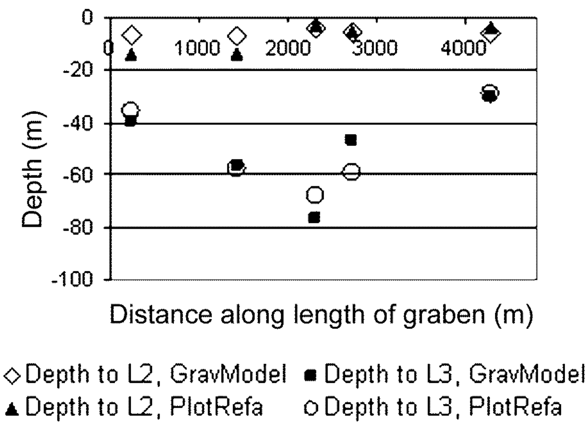

Figure 1. Midpoint of Seismic Line vs. Average Depth (m). South to north is left to right.

Figure 2 shows the corrected and linearly detrended gravity data. Bedrock densities of 2.5 g cm^{-3} and 2.6 g cm^{-3} are both appropriate for the reasonably compact and well cemented sandstone present in the area. Bouguer corrections were completed using both values in order to assess how much impact a slight variation in the density of the bedrock could have on the overall anomaly. Because the results reflecting a Bouguer density of 2.5 g cm^{-3} were so similar to those reflecting a Bouguer density of 2.6 g cm^{-3}, gravity modeling was based on the 2.5 g cm^{-3} dataset only.

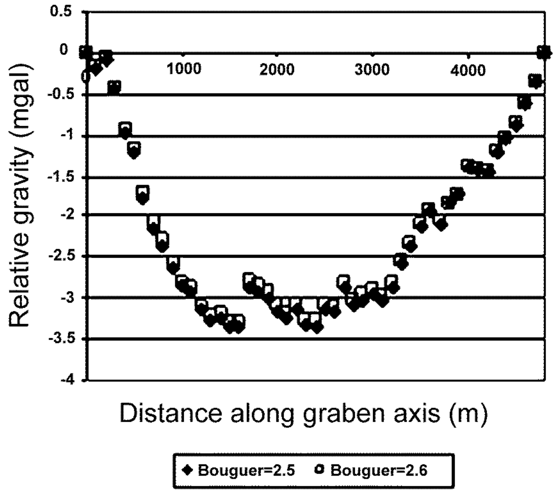

Figure 2. Position along length of graben (m) vs. Relative gravity (mGal). South to north is left to right.

If we assume the depths inferred from the results of the seismic analyses are correct, the seiment density would have to be about 1.25 g cm^{-3} to produce a gravity signature that fits the magnitude of the gravity anomaly (see figures 3-4). 1.25 g cm^{-3} is clearly an implausible density for the sediment as it is only slightly higher than the density of water and implies a porosity of almost 50% (assuming that the sediment is mostly quartz).

When modeling a layer of sediment and a layer of bedrock, a more reasonable density contrast of -0.4 g cm^{-3} between the two materials is only achieved with a maximum sediment depth of approximately 260 m (see figures 5-6). Grosfils et al. (2003) used a density contrast of -0.25 g cm^{-3} when modeling gravity in Devils Lane and thus, -0.4 g cm^{-3} is likely still on the large end of acceptable density contrasts. This model implies that the density of the sediment is about 2.1 g cm^{-3} and that the porosity is about 20%. This is reasonable given that the sediment is likely more tightly packed due to loading than truly unconsolidated sand (Grosfils et al., 2003). However, even with a density contrast on the large end, the sediment in this model (Fig. 3) is more than three times as thick at its maximum as the maximum thickness of the sediment layer suggested by the seismic data.

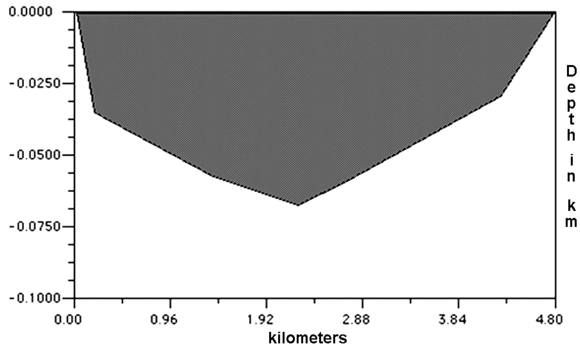

Figure 3. Model representing results of PlotRefa seismic analysis

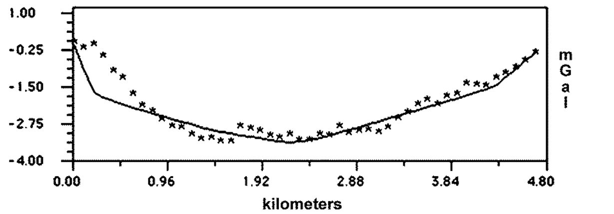

Figure 4. Solid line is the gravity signature produced by the model in figure 3; stars are the observed gravity anomaly (after corrections, etc.)

Assuming the raw seismic data are correct, and the models produced are at least of the approximate appropriate magnitude, there are two possible ways to account for the discrepancy between the models suggested by the seismic data and the models suggested by the gravity data. The first is simply that the gravity data may be wrong. Only one gravimeter was used in the field, and thus the accuracy of the instrument can be questioned. The second possibility is that there is material in the subsurface, in addition to the top layer of sediment, which is also of lower density than the bedrock, and thus contributes to a negative gravity signal.

The most geologically reasonable model for such a situation is one that includes a salt dome. The rock exposed in the Canyonlands grabens is predominantly the Cedar Mesa Sandstone, which is underlain by other sedimentary deposits from the Rico and Hermosa formations. The total thickness of the sedimentary sequence is about 450 m, and it is underlain by the Paradox evaporites, which consist mainly of low-density gypsum and anhydrite (Huntoon, 1982). Both Moore and Schultz (1999) and Shultz-Ela and Walsh

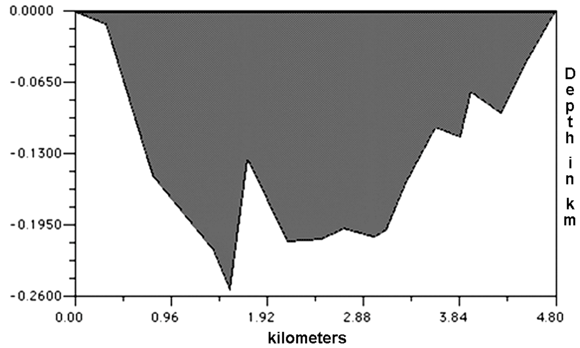

Figure 5. Model that best fits the observed gravity anomaly with a density contrast of -0.4 gcm^{-3}.

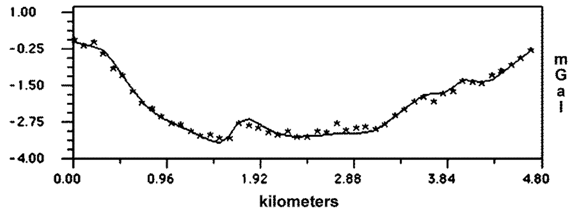

Figure 6. Solid line is the gravity signature produced by the model in figure 5; stars are the observed gravity anomaly (after corrections, etc.)

(2002) have modeled the presence of salt domes rising up beneath graben floors (at least in large grabens such as Red Lake Canyon and Cyclone). Because the evaporite layer is less dense than the overlying sedimentary rock, an upwelling dome of salt beneath a graben could plausibly contribute to a negative gravity signature.

Figures 7-8 show a subsurface model and its associated gravity anomaly that incorporate both a sediment layer at the surface, and a salt dome at depth. A density contrast of -0.4 g cm^{-3} was used for the sediment at the surface as in the previous model (figures 5-6); however, in this model the general geometry of the sedimentary layer reflects the results of the PlotRefa seismic analysis. A contrast of -0.3 g cm^{-3} was assumed for the salt dome because the density of the Paradox evaporites is about 2.2 g cm^{-3} (Schultz-Ela and Walsh, 2002) and the bedrock density was assumed to be approximately 2.5 g cm^{-3}. Moore and Schultz (1999) presented a model of a salt diaper under Devils Lane that offset the top of the evaporite layer by about 40 m, and stated that such upwellings in larger grabens such as Cyclone may be much larger. The magnitude of this diaper is approximately 200 m, but will be slightly reduced if a higher (but still plausible) density contrast is used in the model. The exact geometry of likely salt domes is not known at this point, but this model is at least within reason.

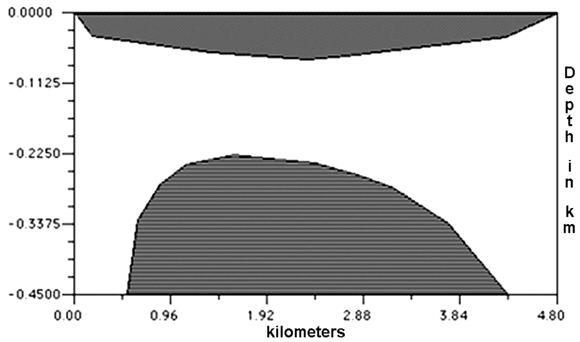

Figure 7. Model including PlotRefa estimates for sediment thickness (top) and salt dome (bottom).

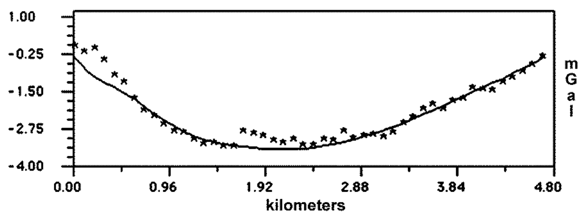

Figure 8. Solid line is the gravity signature produced by the model in figure 7; stars are the observed gravity anomaly (after corrections, etc.)

While figure 7 is an example of a model that both agrees with the seismic interpretation (on a rough scale, given that only five data points were used) of the depth to bedrock, and produces a reasonable fit to the gravity anomaly with reasonable density contrasts, it is important to keep in mind that gravity data are non-unique in that many subsurface models can yield the same set of gravity data.

CONCLUSIONS

There is a discrepancy between the models produced by seismic and gravity data analyses when a model based only on a layer of sediment overlying bedrock is used. However, there is at least one model, which includes a salt dome at depth, that can fit both sets of data at a rough scale and is also geologically plausible. While it is still possible that either the gravity or seismic data are incorrect, it is important that the plausible model based on our geophysical data supports previous numerical models based on structural and mechanical analyses (Moore and Schultz, 1999 and Schultz-Ela and Walsh, 2002). Therefore, it is important to go back into the field to verify the data in order to confirm the validity of the model presented here.

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