HOW DEEP IS THE SANDBOX? MEASURING SEDIMENT DEPTH USING GRAVITY RECONNAISSANCE IN UTAH'S CYCLONE GRABEN

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INTRODUCTION

A system of grabens has developed in the Needles District of Canyonlands National Park, Utah (Fig. 1). In this region, Pennsylvanian and Permian sandstone overlies evaporites of the Pennsylvanian Paradox Formation. Lateral support for these rocks was removed by the incision of a deep canyon by the Colorado River. This has produced a series of normal faults whose movement is facilitated by the low-strength evaporite layer. Accurate estimates of fault displacements require knowledge of sediment thickness within these grabens. Until recently, sediment thickness was estimated to be between 5-15 m. Using geophysical techniques Grosfils et al. (2003) concluded that sediment thickness exceeded 90 m in northern Devils Lane graben. Devils Lane graben is located directly to the east of our project area. Our gravity surveys performed in coordination with seismic studies indicate that the maximum sediment depth in Cyclone graben is approximately 90 m. The discovery of similar sediment depths in the two grabens indicates that the amount of sediment in the Canyonlands grabens greatly exceeds previous estimates. This means more displacement has occurred on the graben faults than was previous thought.

METHODS

Data Acquisition

Our gravity data was measured at 49 stations that were located approximately every 100 m lengthwise (SW-NE) along the axis of the graben. The relative horizontal and vertical locations of the stations were measured using a Leica TPS 405 total station and TDS Recon data collector with SurveyPro 4.0 software.

Figure 1. Cyclone graben is located in the Needles District of Canyonlands National Park, Utah. The graben is over 4 km in length.

The surveyed locations were georeferenced with WAAS corrected GPS data from a Trimble GeoXT. A Lacoste & Romberg Model G gravimeter with Aliod nulling was used to collect the gravity measurements at each station (Fig. 2). Measurements were repeated at gravity base stations at least every hour to account for tidal and instrument drift.

Data Reduction

The initial base station (1000) was used as the datum when performing corrections for latitude, elevation and topography. Latitude and Free-Air correction constants were calculated for the latitude of the survey and partial Bouguer corrections were calculated for densities of 2.4, 2.5, and 2.6 g/cm^3. These were chosen as a reasonable range of possibilities for well consolidated and cemented quartz sandstone (Burger, 1992).

Figure 2. Alice Waldron collecting gravity data using the Lacoste & Romberg Model G meter with Aliod 100 nulling system.

Terrain corrections were calculated using the computer program HAMXYZ2™ from Gradient Geophysics and digital elevation data. The digital elevation data was acquired from the National Elevation Dataset (NED) through the USGS Seamless Data Distribution System. Both 1 arc second (approximately 30 m) and 1/3 arc second elevation data were acquired. ESRI ArcGIS Spatial Analyst was used to project both elevation data sets into UTM (NAD83 Zone 12N) coordinates and resample them to 30 m and 10 m resolutions respectively.

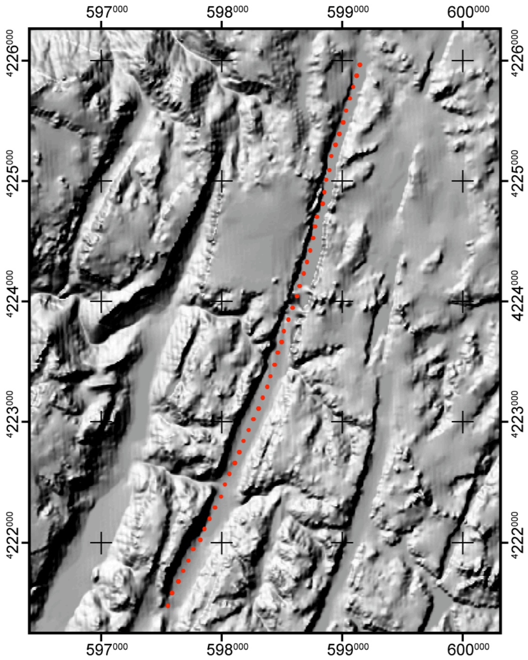

Figure 3. Gravity stations shown on shaded relief of 10 m elevation data. Coordinates are UTM Zone 12N NAD83.

HAMXYZ2™ is an implementation of the method proposed by Hammer (1939). The inner and outer radii of the zones and the number of sectors per zone are customizable and are specified in a control file, Hammer.con. After projection of the elevation data, our surveyed locations registered very accurately against the 10 m data (Fig. 3), and somewhat less accurately against the 30 m data.

Given the limited accuracy of the NED digital elevation data which can be as poor as ± 7 meters, I chose to ignore all Hammer zones closer than 17 m to each gravity station. We took care in locating the gravity stations to minimize topography near each station. Given the locations of the stations along the axis of the graben floor, elevations within 17 m of each station seldom varied by more than 1 m.

I chose to use the 10 m elevation data for the inner Hammer zones ranging from a radius of 17 m to 390 m from each gravity station. These inner Hammer zones are as follows:

Zone	**Inner Radius**	**Outer Radius**	**Sectors**
C	17 m	53 m	6
D	53 m	170 m	8
E	170 m	390 m	8

To manage the size of the ASCII elevation files required by HAMXYZ2™, 30 m elevation data were used for the outer Hammer zones extending to 6652 m from each gravity station. These zones are as follows:

Zone	Inner Radius	Outer Radius	Sectors
F	390 m	895 m	8
G	895 m	1529 m	12
H	1529 m	2614 m	12
I	2614 m	4469 m	12
J	4469 m	6652 m	16

A buffer operation in ArcGIS was used to crop each elevation data set to the appropriate maximum radius from all gravity stations. Each elevation data set was then exported to ASCII XYZ format for use with HAMXYZ2™.

I calculated three terrain corrections in HAMXYZ2™ using sandstone densities of 2.4, 2.5, and 2.6 g/cm^3. These were then added to the Bouguer anomaly with the corresponding density to produce final anomalies for all three densities (Fig. 4). As shown in the figure, the choice of bedrock density has little effect on the shape or amplitude of the Bouguer anomalies or terrain corrections.

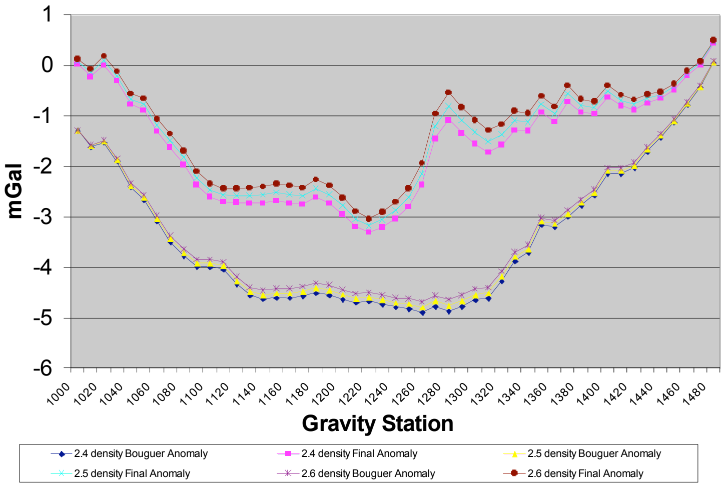

Figure 4. Bouguer and final anomalies (with terrain corrections) comparing calculations for sediment densities of 2.4 2.5, and 2.6 g/cm3.

A relative gravity high is produced by the terrain corrections near station 1300. Examination of the digital elevation data shows that this high is produced by the elevation of a large talus pile in the graben near this gravity station. The density of this talus is probably significantly lower than solid bedrock but the HAMXYZ2™ software cannot accommodate varying densities beneath the elevation surface so this local peak is probably an artifact that needs to be ignored in the modeling of the gravity anomaly.

Modeling

The gravity anomalies were modeled using GM-SYS, a gravity/magnetic modeling software. This software will model a maximum of 35 stations. Our gravity data was collected from 49 stations so I selected 35 that provide the best representation of the anomaly. A density of 2.0 g/cm^3 was chosen to model the sediment fill. The density for the sandstone bedrock was entered as 2.5 g/cm^3 and salt was modeled at 2.0 g/cm^3 (Burger, 1992).

Figure 5 shows a simple model (with no salt) that fits the gravity anomaly. Notice that the model does not fit the relative gravity high at approximately 3000 m, which corresponds to the terrain correction artifacts near station 1300.

The model in Figure 6 explores possible involvement of the salt layer and is constrained by seismic refraction data. The gravity high near station 1300 was also ignored in this model.

DISCUSSION

Modeling of the reduced gravity data without salt (Fig. 5) indicates that sediment fill in the graben is relatively thin (50-60 m) throughout the northern half. There is an abrupt thickening to approximately 300 m near the middle of the graben. The southern half has thicker sediment fill than the northern half with typical depths between 100 and 150 m.

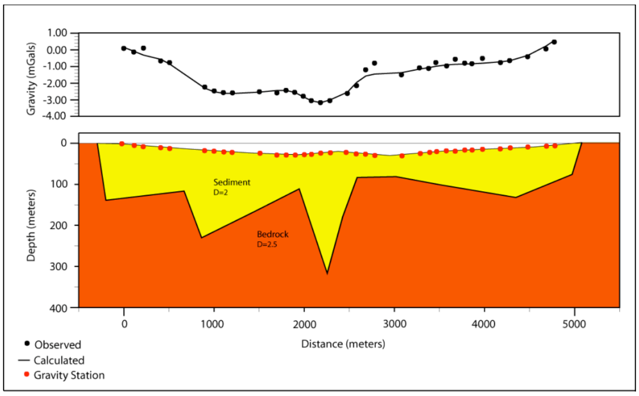

Figure 5. Model of gravity data without diapiric upwelling using sandstone bedrock density of 2.5 g/cm3 and sediment density of 2.0 g/cm3.

The maximum sediment thickness in the model is about 300 m near the center of the graben. Field observations indicate that the master fault may switch from the eastern wall of the graben in the north to the western wall south of this point. The differences in sediment thickness between the northern and southern halves of the graben and the abrupt transition at the midway point may correspond with the fault switch.

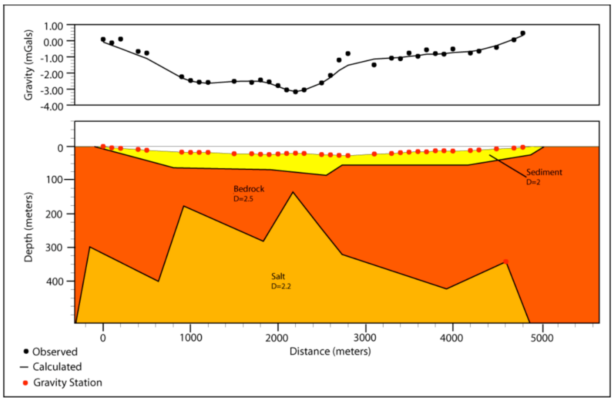

Figure 6. This model investigates the use of a salt diapir (2.2 g/cm3) to decrease sediment depth.

The sediment thickness calculated for the southern half of Cyclone graben disagrees significantly with results obtained from seismic refraction studies in the graben (Abrahamson, Dibiase, Michaels, Trenton and Waldron, cf. this volume). The seismic results indicate thicknesses of 45-70 m while the gravity models (without salt) suggest thicknesses up to 150-300 m.

There is little chance of significant error in the processing and modeling of the gravity data since independent gravity reduction and terrain calculations performed by Waldron (cf. this volume) yield similar results. The discrepancy between the gravity and seismic results may be caused by a diapiric upwelling of salt beneath the graben floor. The model in Figure 6 shows that this is a plausible explanation.

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