

Constraints on the SCEC 3D Velocity Model from Gravity Data:  
Two-Dimensional Gravity Modeling of the Central and Eastern  
Transverse Ranges in the Los Angeles Region



Nancy Natek  
The University of New Mexico

# Constraints on the SCEC 3D Velocity Model from Gravity Data: Two-Dimensional Gravity Modeling of the Central and Eastern Transverse Ranges in the Los Angeles Region

Nancy Natek  
The University of New Mexico  
Department of Earth and Planetary Sciences  
Albuquerque, NM 87131-1116

Advisor  
Dr. Mousumi Roy

September 29, 2000

Research sponsored by  
Southern California Earthquake Center

## TABLE OF CONTENTS

ABSTRACT	5
INTRODUCTION	6
<u>The SCEC 3D Velocity Model</u>	6
METHODOLOGY	6
<u>Data</u>	7
DISCUSSION	10
<u>Airy Compensation Models</u>	10
<u>Gravity Modeling</u>	10
<u>Velocity Models</u>	11
<u>Density Models</u>	11
<u>Gravity Models</u>	25
CONCLUSIONS	32
ACKNOWLEDGEMENTS	32
BIBLIOGRAPHY	33

## ILLUSTRATIONS

Cover Photo: Mt. San Gorgonio of the San Bernadino Mtns. looking toward the northeast across Highway 10 near Mt. San Jacinto.

Figure		Page
1	Gravity Profile of the Study Area	8
2	Bouguer Gravity for the Study Area	9
3	Airy Compensation Model and Predicted Gravity for Profile 1	12
4	Airy Compensation Model and Predicted Gravity for Profile 2	13
5	Airy Compensation Model and Predicted Gravity for Profile 3	14
6	Airy Compensation Model and Predicted Gravity for Profile 4	15
7	Revised Predicted Gravity for Profile 4	16
8	Velocity Model for Profile 1	17
9	Velocity Model for Profile 2	18
10	Velocity Model for Profile 3	19
11	Velocity Model for Profile 4	20
12	Density Model for Profile 1	21
13	Density Model for Profile 2	22
14	Density Model for Profile 3	23
15	Density Model for Profile 4	24
16	Best Fit for Profile 2	26
17	Best Fit Inside the LA Basin for Profile 2	27
18	Best Fit Outside the LA Basin for Profile 2	28
19	Best Fit to the Mojave Desert for Profile 2	29
20	Density Structure for the Mojave Desert	30
21	Best Fit to the Mojave Desert for Profile 2	31

Happy the man whose lot is to know  
The secrets of the Earth.  
--Euripides (480-405)

## **ABSTRACT**

The goals of this project are to test the consistency of crustal seismic velocity structure and gravity data in the Transverse Ranges. Following earlier work by Roy and Clayton, we use 2D gravity models based on density structures inferred from crustal tomography. We use version 2 of the Southern California Earthquake Center (SCEC) velocity model and an empirically derived scaling relation between seismic velocities and density. The density structures thus inferred are used to forward model gravity along 2D profiles.

We plan to compare predicted gravity along four 2D topographic profiles across the central and eastern Transverse Ranges to the observed gravity. This report shows our preliminary results for one of the profiles and work in progress on the other three profiles. We find that, in general, gravity data and crustal tomographic structures are consistent with each other. However, we find that there are significant misfits in the eastern LA Basin and in the Mojave Desert. In order to obtain a good fit in the LA Basin, we were required to increase average densities in the basin, reducing the size of the negative Bouguer signal from basin sediments. The gravity anomaly in the Mojave Desert section of the profile is more negative than predicted, suggesting the presence of a subsurface crustal mass deficit. This region can be well-matched by increasing the depth to the Moho under the Mojave Desert, or, as shown by Roy and Clayton, by reducing average crustal densities in the Mojave.

## **INTRODUCTION**

The Transverse Ranges in southern California are an east-west trending range and are located within the transform plate boundary zone of the North American and Pacific plates. They are the result of recent, transpressional plate boundary tectonics in which the strike-slip San Andreas fault system formed a constraining, or compressive bend, resulting in the upthrusting of segments of crust producing high mountains. Uplift of the Transverse Ranges by north-south compression began ~5 Myr ago (Atwater, 1970). The goal of this project is to understand the compensation mechanisms that support high topography in the Transverse Ranges and to provide an independent geophysical constraint on seismic tomography.

Following Roy and Clayton (2000) we analyze 2D gravity models based on version 2 of the Southern California Earthquake Center (SCEC) 3D velocity model. In this study, we chose four 2D profiles across the central and eastern Transverse Ranges (Figure 1) and compare predicted gravity to observed gravity (Figure 2) along the profiles.

### **The SCEC 3D Velocity Model**

The 3D seismic velocity model for Southern California in the Los Angeles region is a crustal tomographic model of P-wave and S-wave velocities reflecting density structures developed in 1997 (Clayton, 1997). Improvements in Version 2 include shallow (<200m depth)  $V_p$  and  $V_s$  constraints from geotechnical borehole data and an improved background velocity model (Magistrale, et al., in preparation, 2000).

## **METHODOLOGY**

The methodology was developed from previous work by Roy and Clayton. Using raw gravity data sets of free-air and terrain-corrected Bouguer anomalies, the gravity model was

parameterized as a two-dimensional grid with northeast to southwest profiles roughly parallel to the LARSE I line (Langenheim and Jachens, 1999) across the central and eastern ranges (Figure 1). The two-dimensional profiles were compared with Airy compensation models, observed gravity and predicted gravity.

Constructing four two-dimensional southwest to northeast topographic profiles roughly parallel to the LARSE I line across the central and eastern ranges, the profiles were compared with observed gravity. An Airy compensation model was then developed to calculate the Moho deflections of each profile and the models were compared to topography and the observed Bouguer anomaly data. Then using a method to model gravity data in a two-dimensional approach developed by Talwani et al., 1959, a 2D gravity model was constructed and compared with the observed gravity.

Contour plots and slices were made through the SCEC 3D velocity model to obtain the velocity structure of each profile. The density structure for each profile was inferred from the velocities using empirical scaling relations between  $V_p$  and density (Magistrale et al., 1996). The density structure was then used to forward model the predicted gravity along the 2D profiles and compared to the observed gravity thereby providing an independent geophysical constraint on the seismic tomography.

## **Data**

Gravity in the LA region was obtained from a large data set of raw gravity, free-air, and terrain-corrected Bouguer anomalies in Southern California provided by Shawn Biehler at UC Riverside. Seismic velocities are from the current version of the SCEC 3D velocity model (version 2) provided by Harold Magistrale, SDSU.

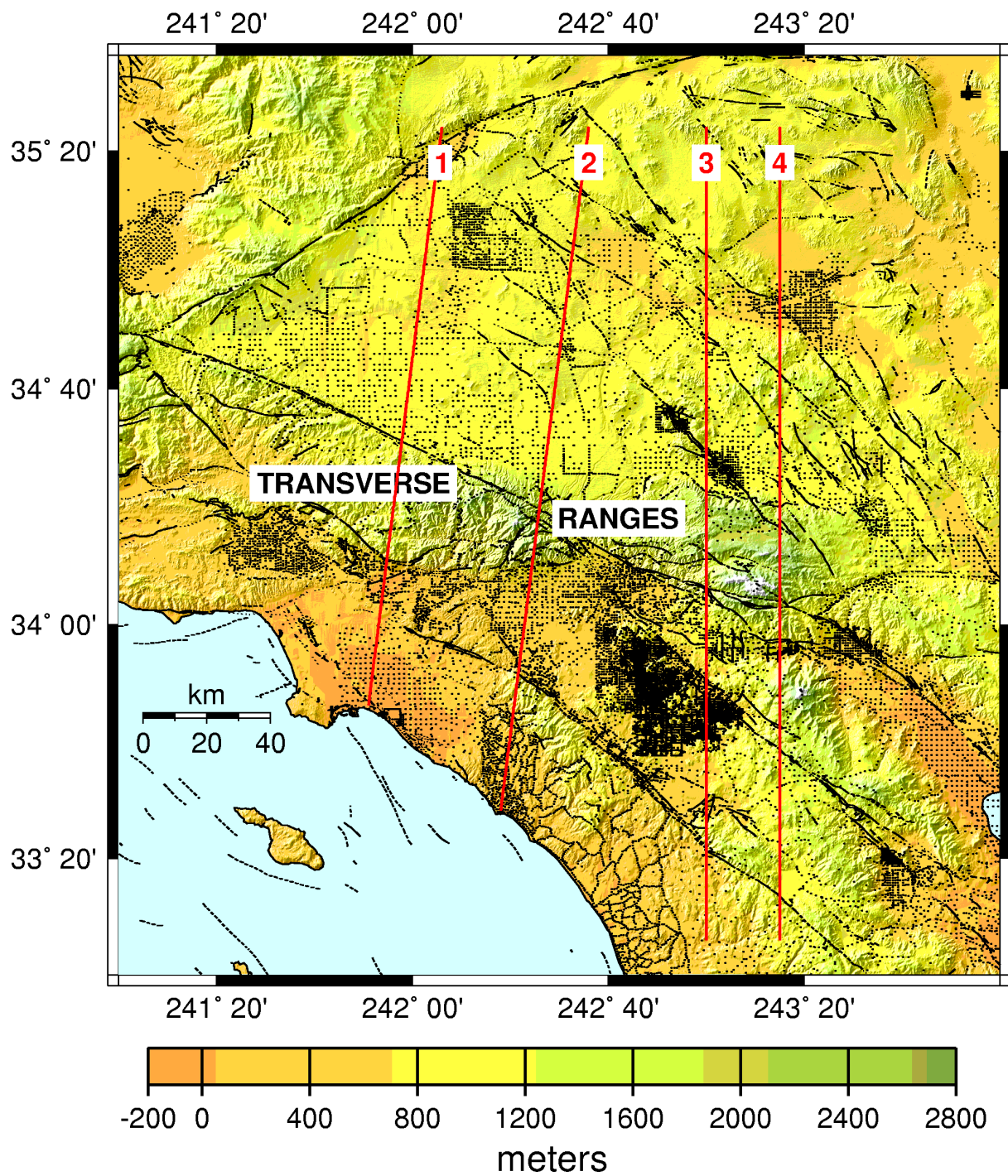


Figure 1. Shaded relief for the study area, with lines showing locations of our four gravity model profiles. Solid black dots represent locations at which the Bouguer gravity anomaly is measured.

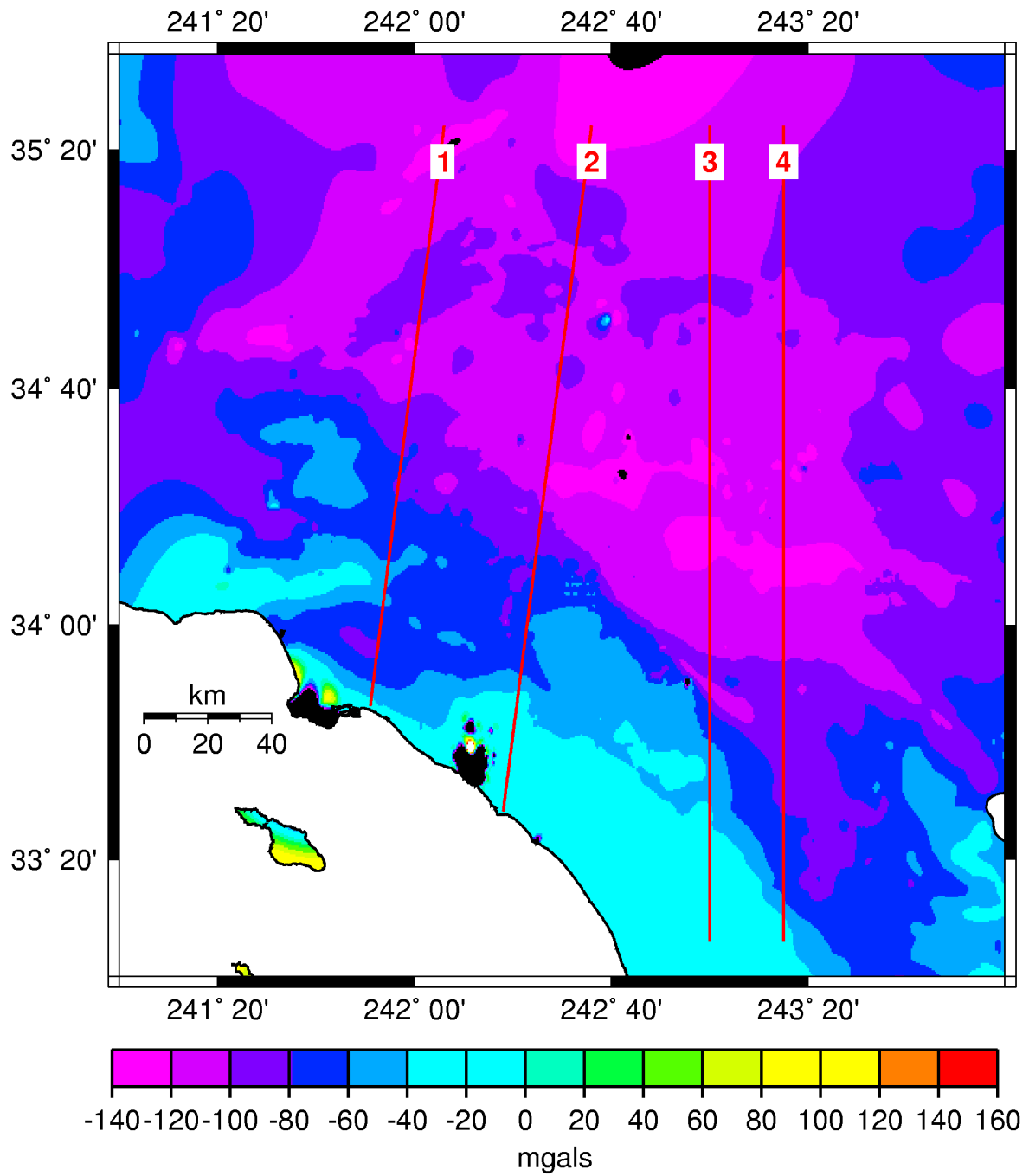


Figure 2. The Bouguer gravity for the study area is obtained from a regional data set of southern California gravity from Professor S. Biehler at UC Riverside.

## **DISCUSSION**

### **Airy Compensation Models**

Mountain ranges are isostatically compensated by a low density crustal root. This crustal root is typically 5 to 8 times the height of the topographic relief and mimics the topography. A mountain of height  $h$  would have a root  $r$  given by:

$$r = \frac{h\rho_c}{(\rho_m - \rho_c)}$$

where  $\rho_c$  = average density of the crust and  $\rho_m$  = average density of the mantle (Fowler, 1990).

We generated four 2D topographic profiles across the central and eastern ranges and used the height of the topography, an average crustal density of 2800 kg/m<sup>3</sup> and an average mantle density of 3300 kg/m<sup>3</sup> to construct an Airy compensation model for each profile (Figures 3, 4, 5 and 6). We also used an average crustal thickness of 25 km. Note that the root mimics the topography.

### **Gravity Modeling**

We used a simple 2D gravity model based on an approach by Talwani et al. (1959) to give us a preliminary look at the predicted gravity before we used the 3D velocity model to forward model the gravity. However there are several assumptions/limitations to this method which include: 1) assuming 2D profiles with no variations of structure perpendicular to the profile, and 2) assuming a very simple uniform density structure for the crust. In calculating the predicted gravity from the Airy compensation models and comparing to observed gravity, we found that the high topography in profiles 1 through 3 in general matched well with the observed gravity with the exception of some mismatched areas of basins in the LA and Mojave desert regions (Figures 3, 4 and 5).

In Profile 4 the observed gravity was much higher than the model predicted (Figure 6). This profile has much more mass than profiles 1 through 3 and we expected a much lower observed gravity due to the predicted low density crustal root. In order to obtain a good fit to the Bouguer gravity in this area we had to reduce the average crustal density (Figure 7). At this time we do not know the cause of this effect, but may have a better understanding when we obtain density profiles from the velocity model. The calculated crustal density variations from the velocity model will be much more accurate than the uniform density structure used for our simple 2D gravity model.

### **Velocity Models**

We made contour plots and slices through the SCEC 3D velocity model version 2 (Magistrale et al., in preparation) to look at velocity structure for each profile. Figures 8, 9, 10, and 11 show the contour plots of p-wave velocities along the 2D profiles. Velocities are contoured at 0.5 km/s intervals.

### **Density Models**

The density structure along the profiles were inferred from the velocities in Figures 8, 9, 10, and 11 using empirical scaling relations between  $V_p$  and density (Magistrale et al., 1996) and are shown in Figures 12, 13, 14, and 15. The density structures  $> 2700 \text{ kg/ m}^3$  are contoured at  $50 \text{ kg/ m}^3$  intervals.

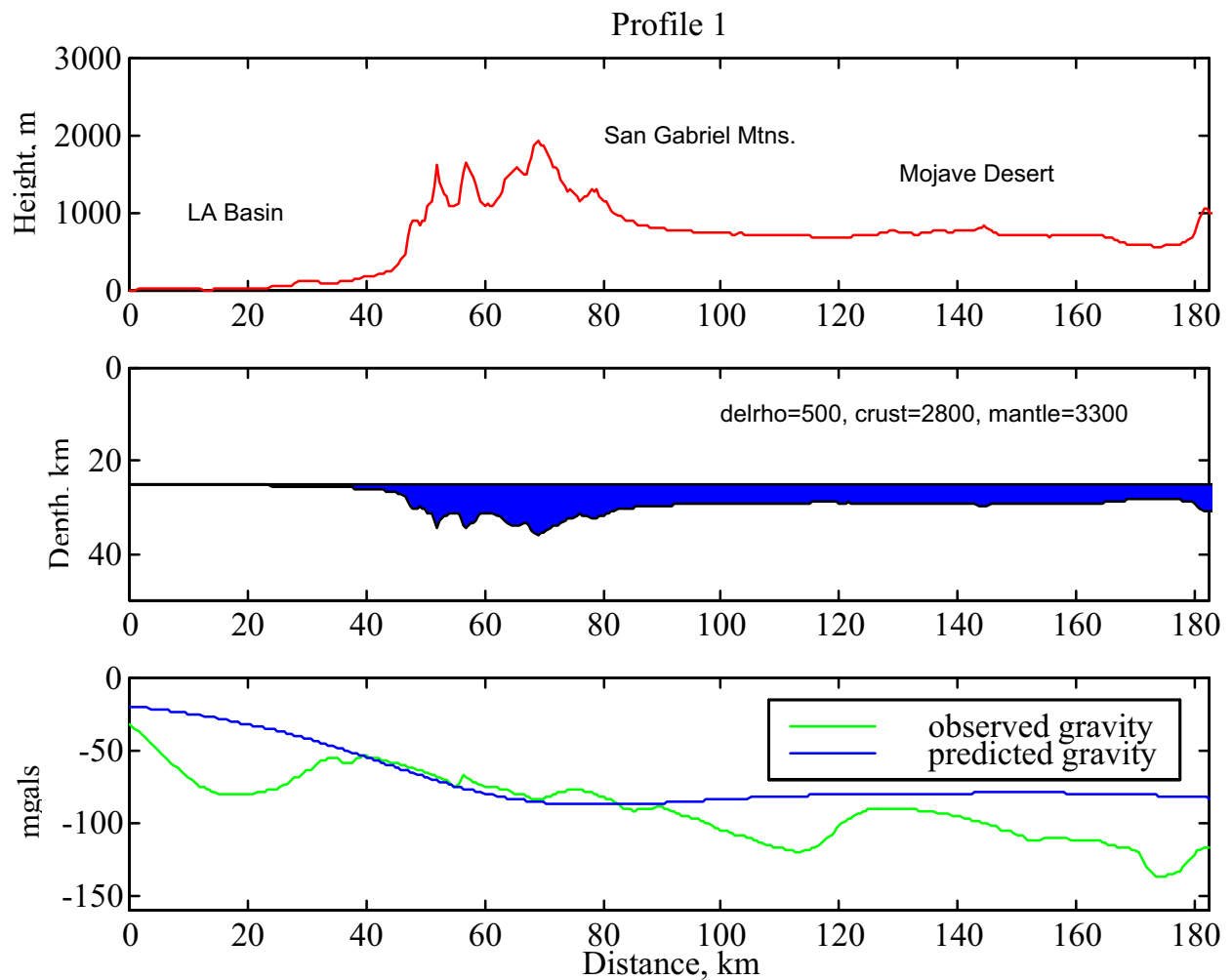


Figure 3(a): Plot of topography along Profile 1 in Figure 1. (b) Airy compensation model. (c) Predicted gravity along Profile 1 with  $\rho_{\text{crust}} = 2800 \text{ kg/m}^3$  and  $\rho_{\text{mantle}} = 3300 \text{ kg/m}^3$  using the Talwani method (Talwani, 1959).

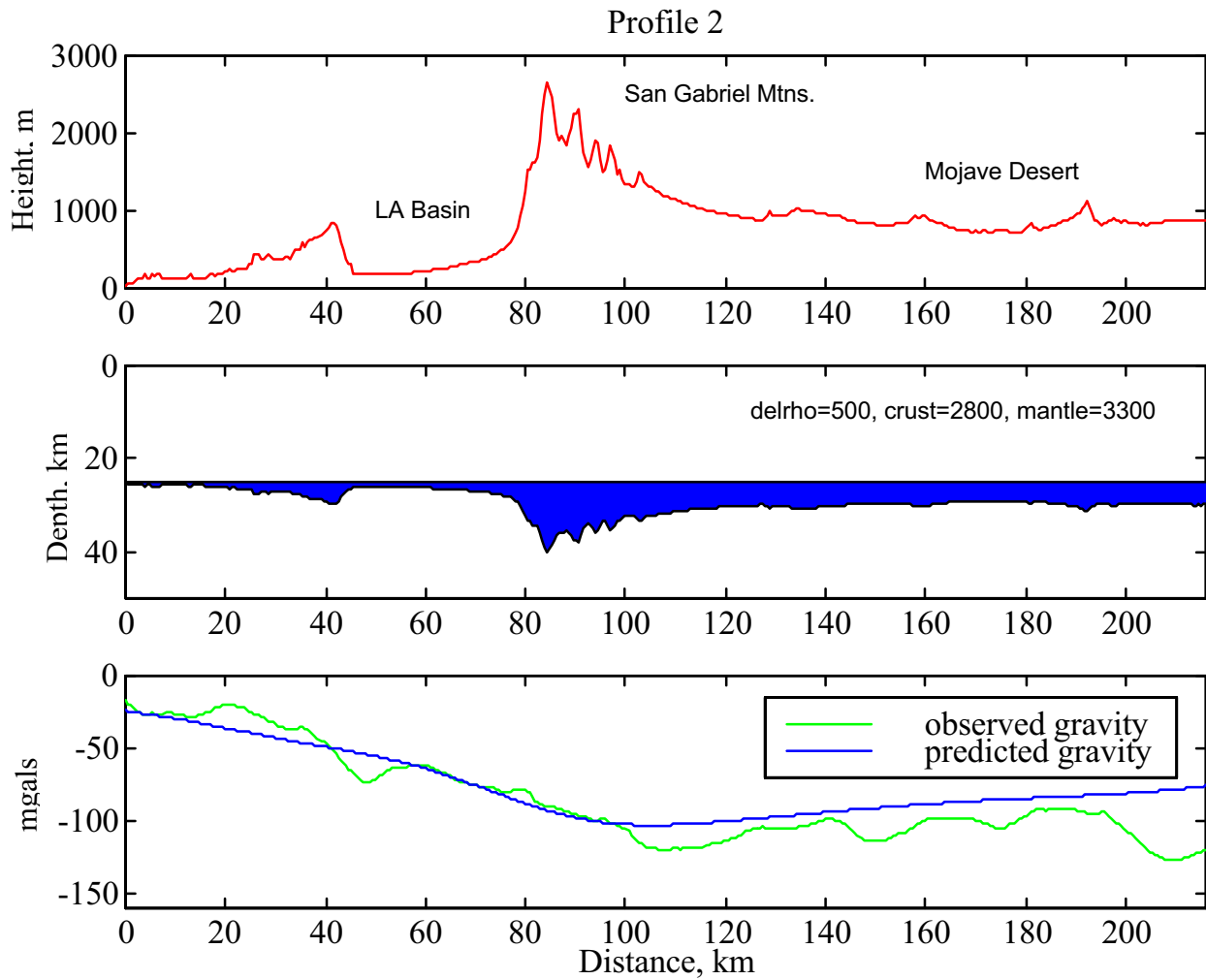


Figure 4(a): Plot of topography along Profile 2 in Figure 1. (b) Airy compensation model. (c) Predicted gravity along Profile 2 with  $\rho_{\text{crust}} = 2800 \text{ kg/m}^3$  and  $\rho_{\text{mantle}} = 3300 \text{ kg/m}^3$  using the Talwani method (Talwani, 1959).

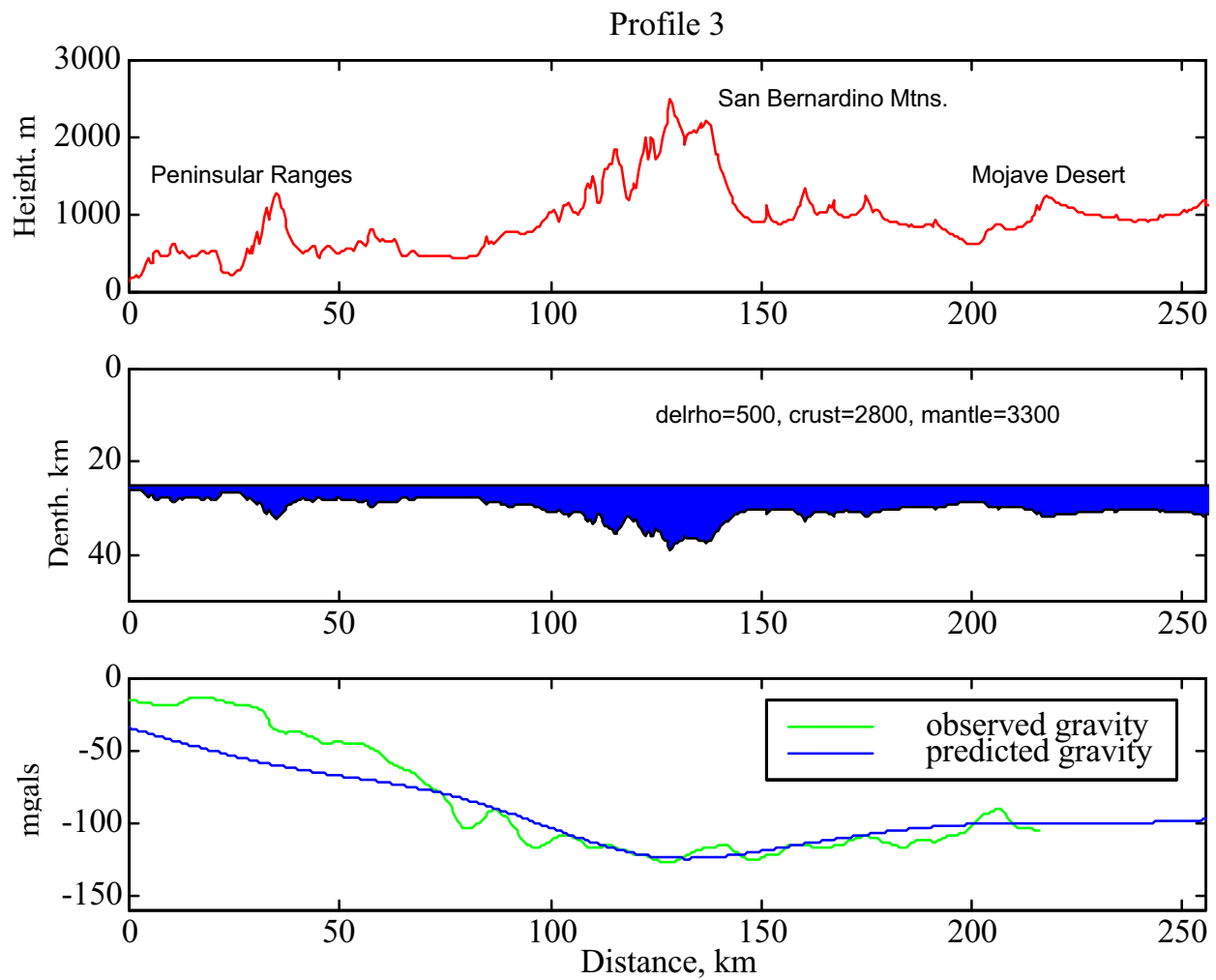


Figure 5(a): Plot of topography along Profile 3 in Figure 1. (b) Airy compensation model. (c) Predicted gravity along Profile 3 with  $\rho_{\text{crust}} = 2800 \text{ kg/m}^3$  and  $\rho_{\text{mantle}} = 3300 \text{ kg/m}^3$  using the Talwani method (Talwani, 1959).

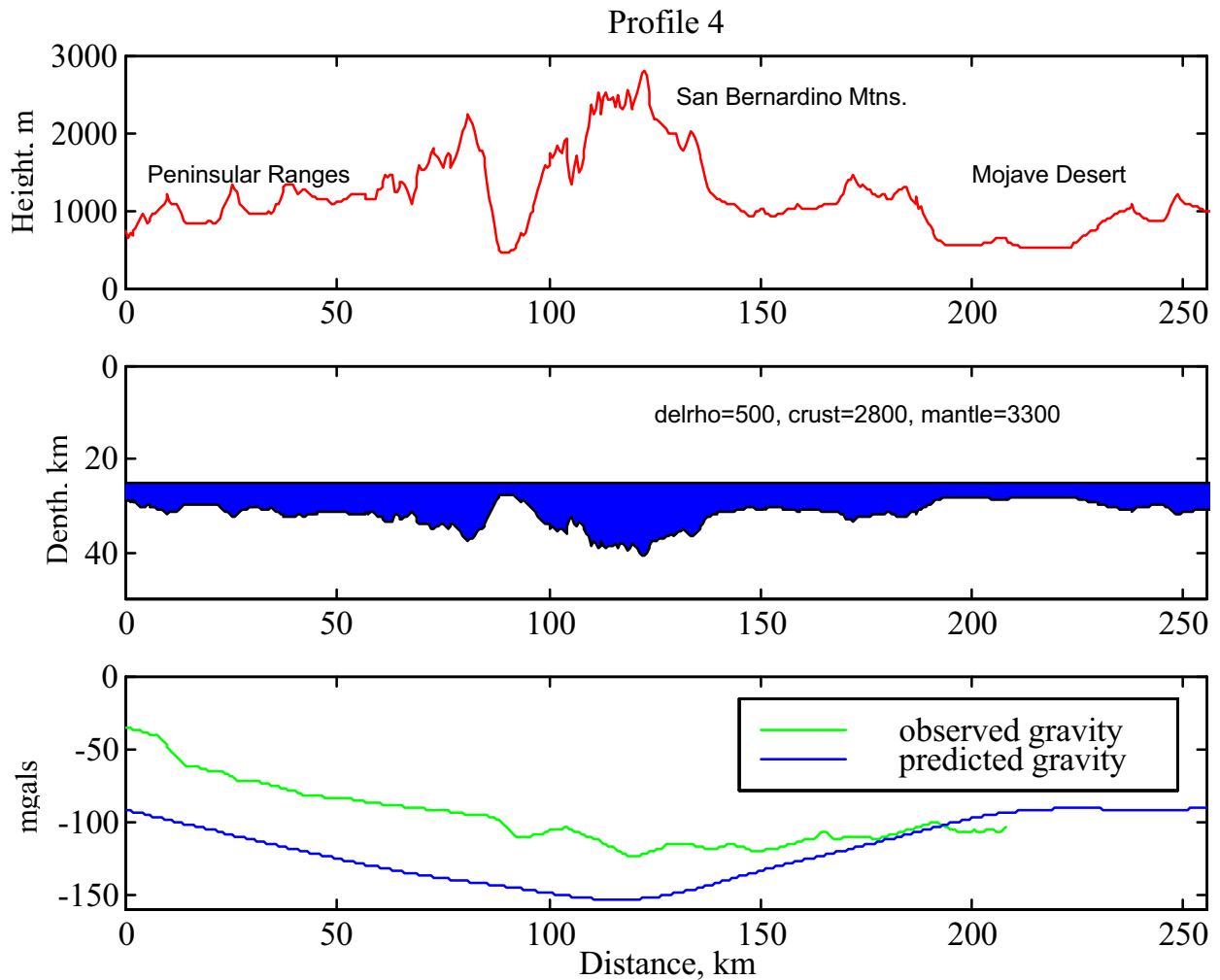


Figure 6(a): Plot of topography along Profile 4 in Figure 1. (b) Airy compensation model. (c) Predicted gravity along Profile 4 with  $\rho_{\text{crust}} = 2800 \text{ kg/m}^3$  and  $\rho_{\text{mantle}} = 3300 \text{ kg/m}^3$  using the Talwani method (Talwani, 1959).

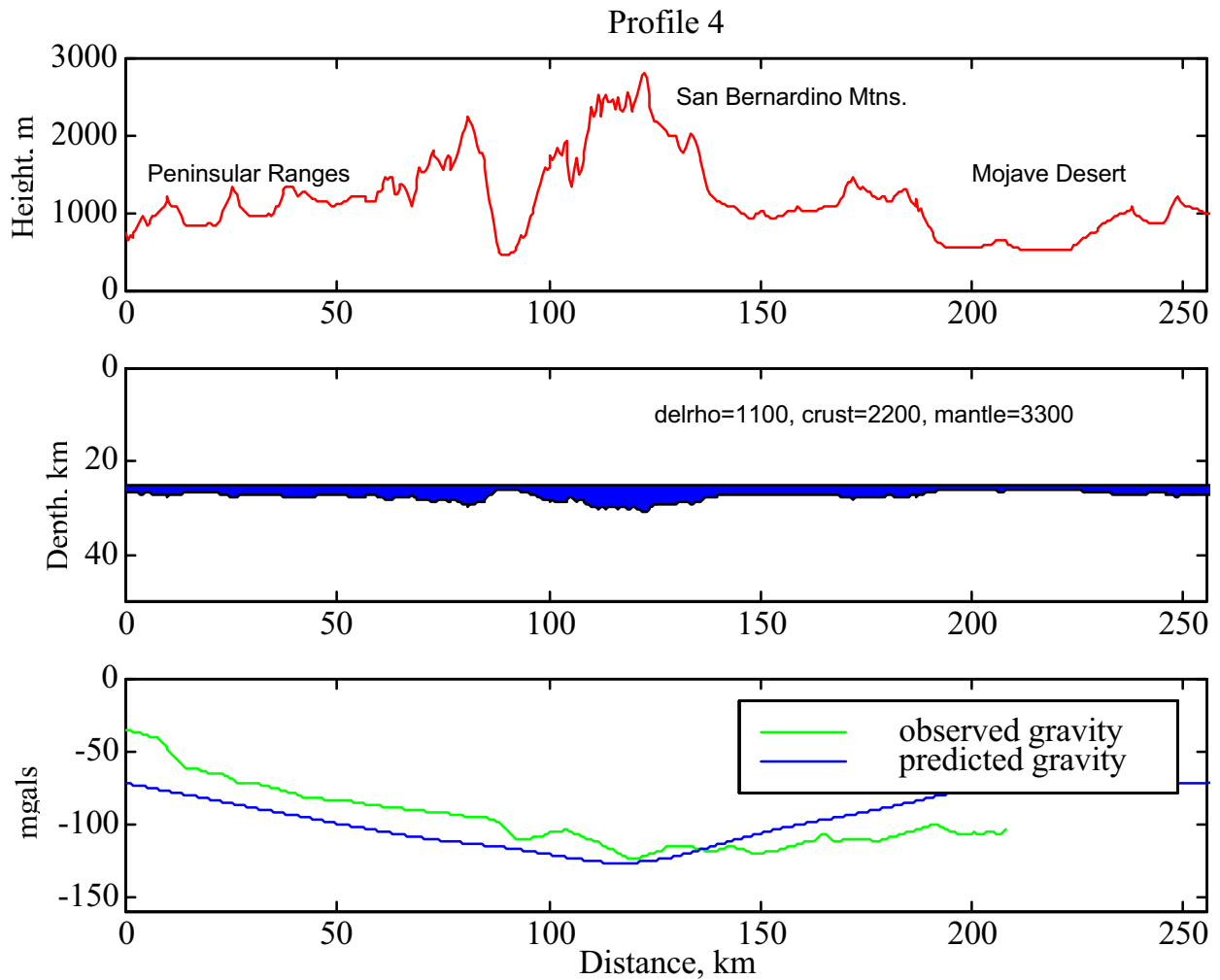


Figure 7(a): Plot of topography along Profile 4 in Figure 1. (b) Airy compensation model. (c) Predicted gravity along Profile 4 with  $\rho_{\text{crust}} = 2200 \text{ kg/m}^3$  and  $\rho_{\text{mantle}} = 3300 \text{ kg/m}^3$  using the Talwani method (Talwani, 1959).

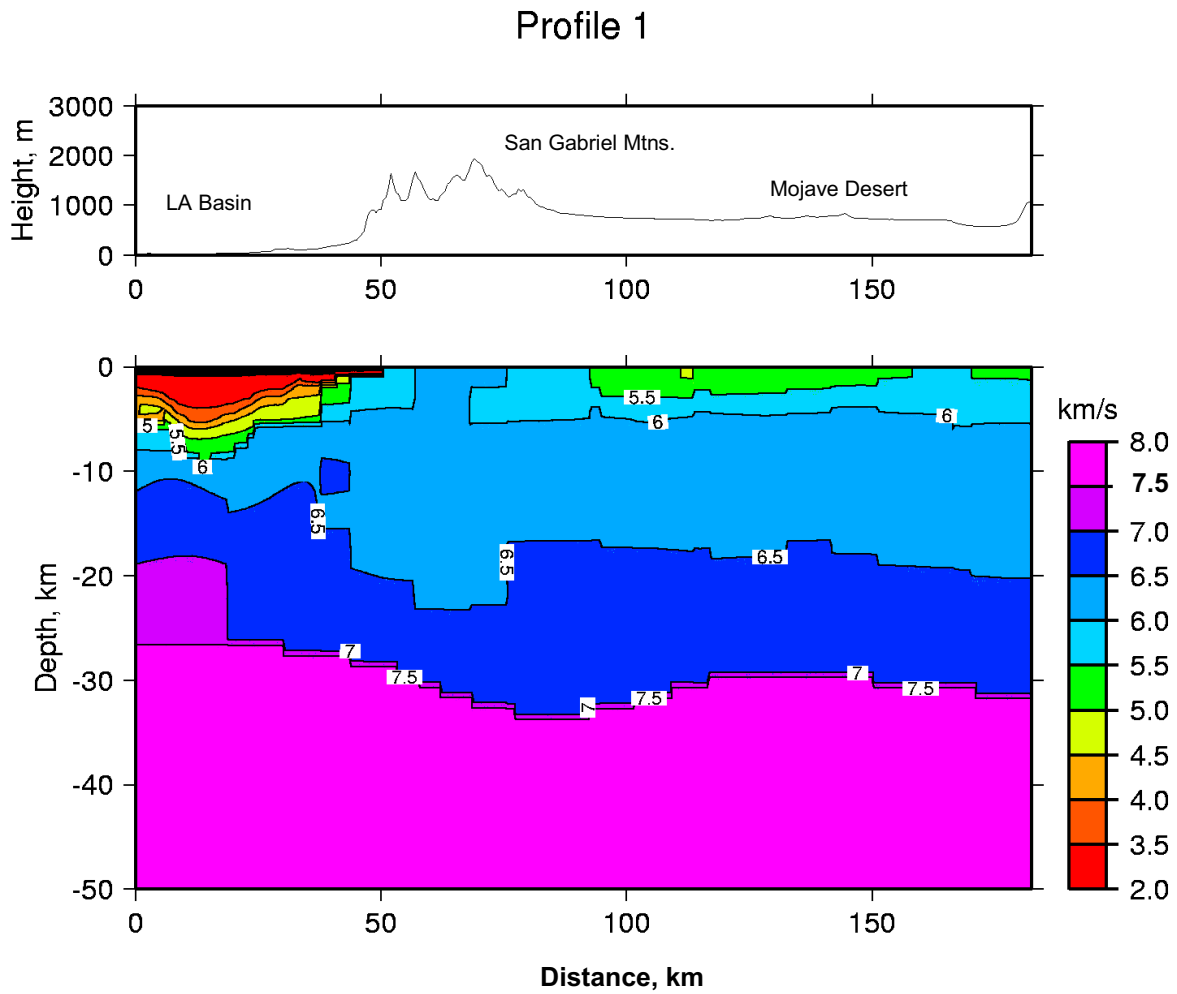


Figure 8 (a). Plot of topography along Profile 1 in Figure 1. (b) Contour plot of p-wave velocities along Profile 1 (Figure 1) from the SCEC 3D velocity model, version 2 (Magistrale et al., in preparation).

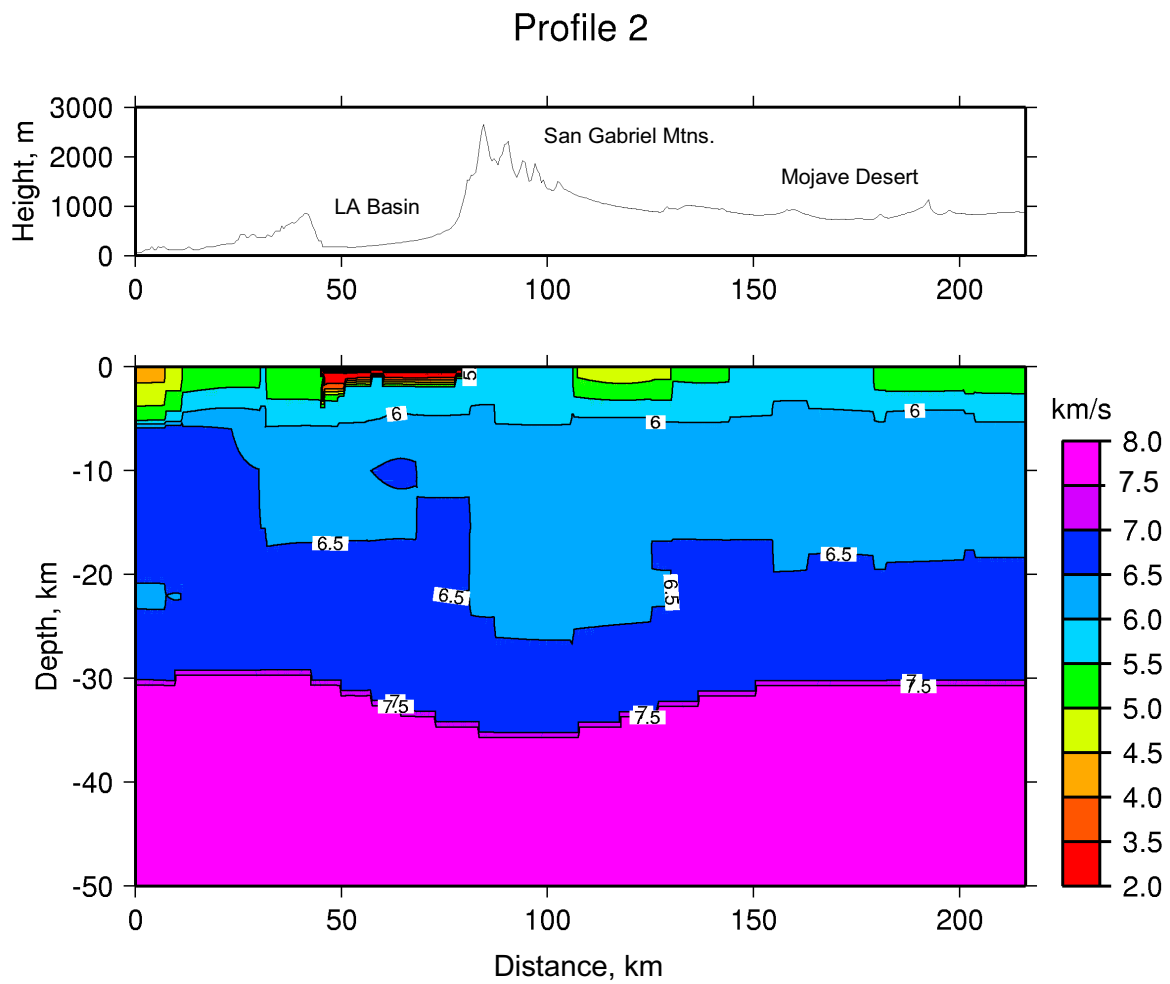


Figure 9 (a). Plot of topography along Profile 2 in Figure 1. (b) Contour plot of p-wave velocities along Profile 2 (Figure 1) from the SCEC 3D velocity model, version 2 (Magistrale et al., in preparation).

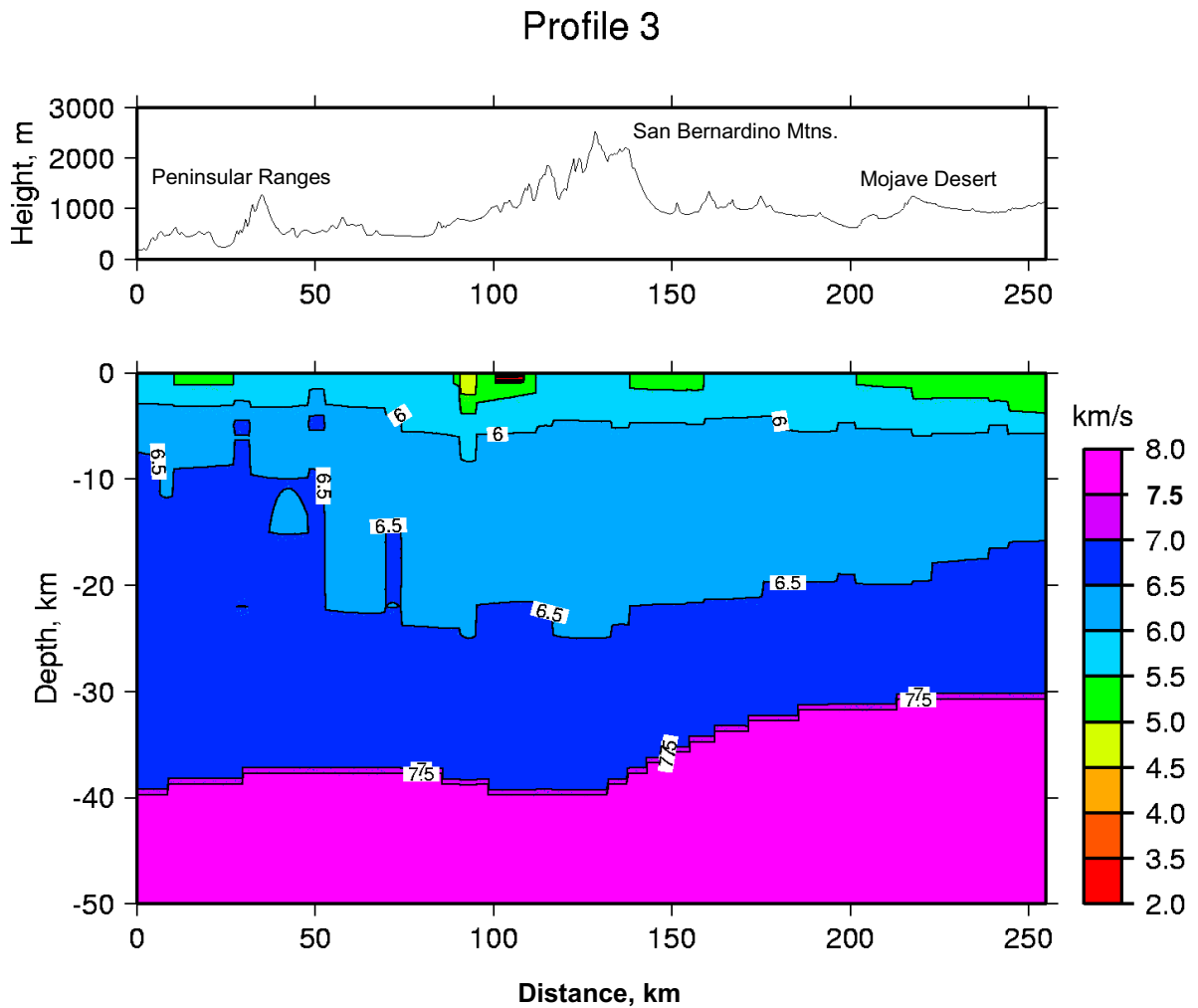


Figure 10 (a). Plot of topography along Profile 3 in Figure 1. (b) Contour plot of p-wave velocities along Profile 3 (Figure 1) from the SCEC 3D velocity model, version 2 (Magistrale et al., in preparation).

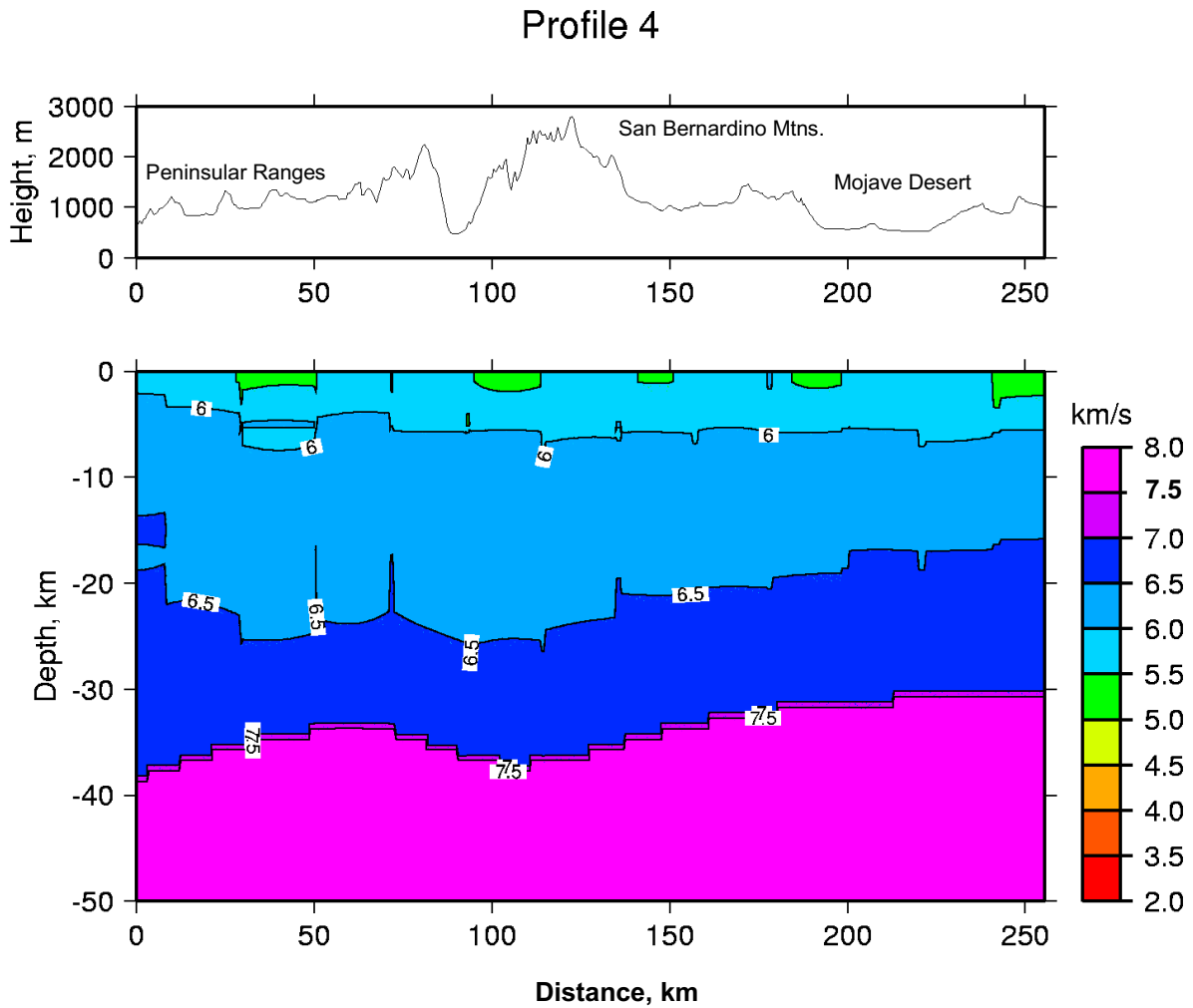


Figure 11 (a). Plot of topography along Profile 4 in Figure 1. (b) Contour plot of p-wave velocities along Profile 4 (Figure 1) from the SCEC 3D velocity model, version 2 (Magistrale et al., in preparation).

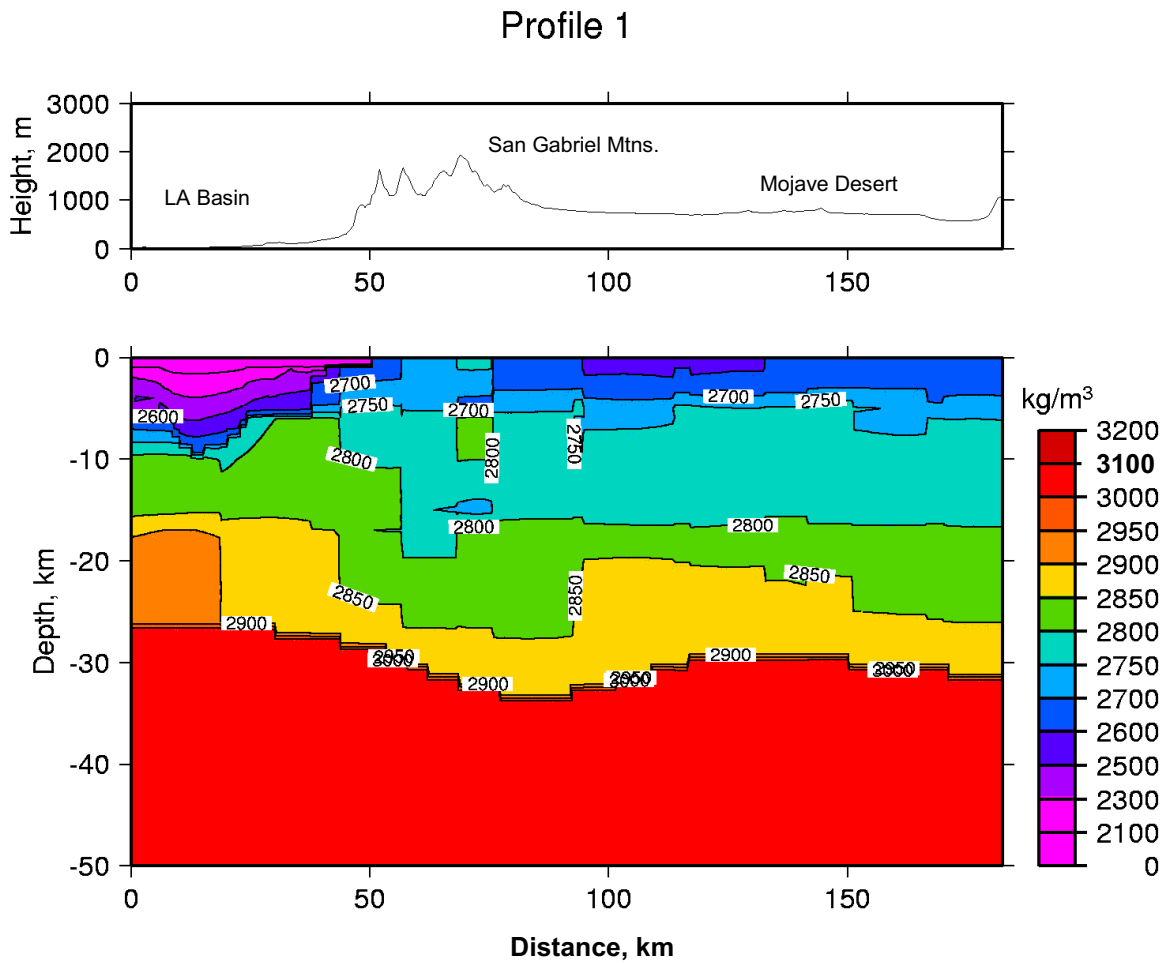


Figure 12 (a). Plot of topography along Profile 1 in Figure 1. (b) Contour plot of densities along Profile 1 inferred from the velocities in Figure 8 using empirical scaling relations between  $V_p$  and density (Magistrale et al., 1996).

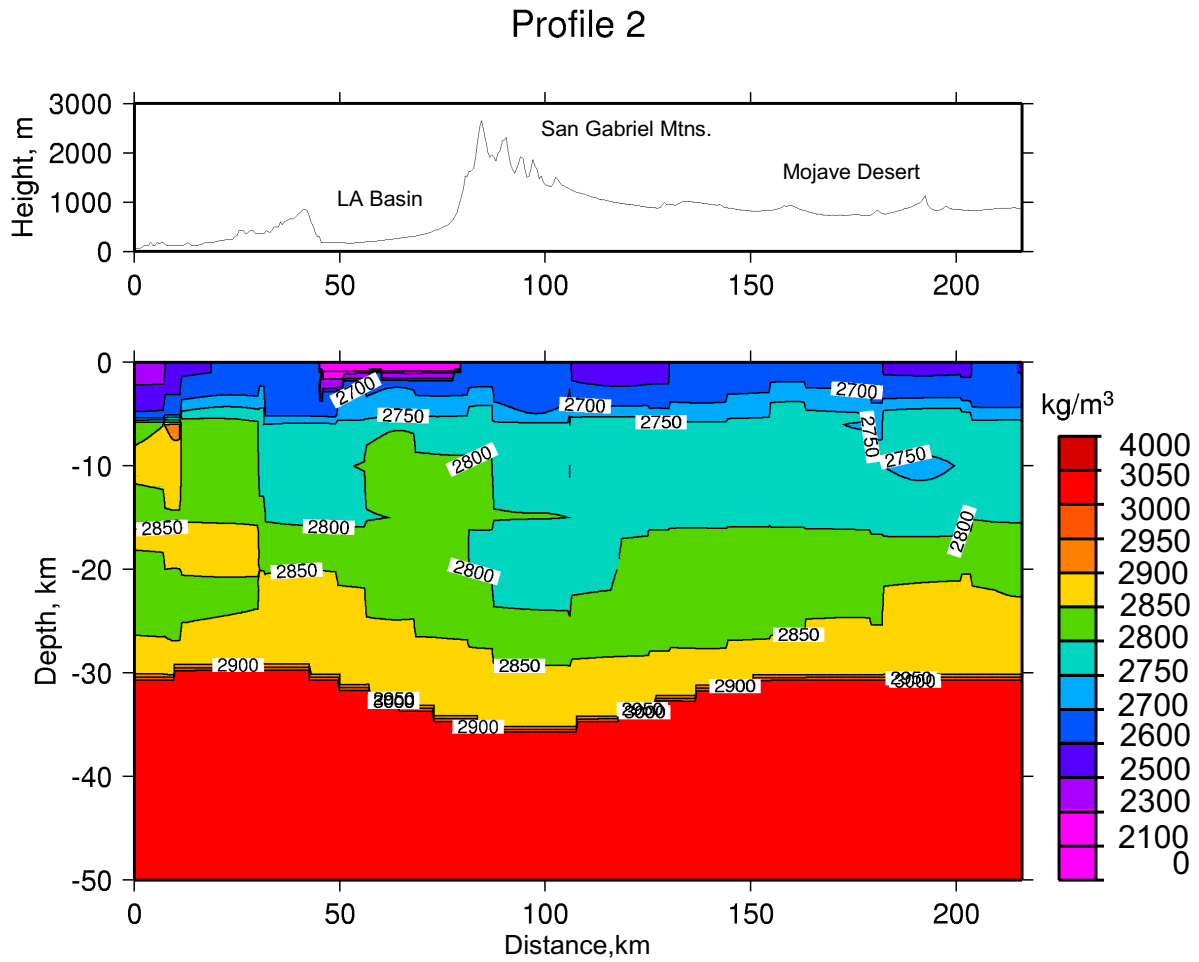


Figure 13 (a). Plot of topography along Profile 2 in Figure 1. (b) Contour plot of densities along Profile 2 inferred from the velocities in Figure 9 using empirical scaling relations between  $V_p$  and density (Magistrale et al., 1996).

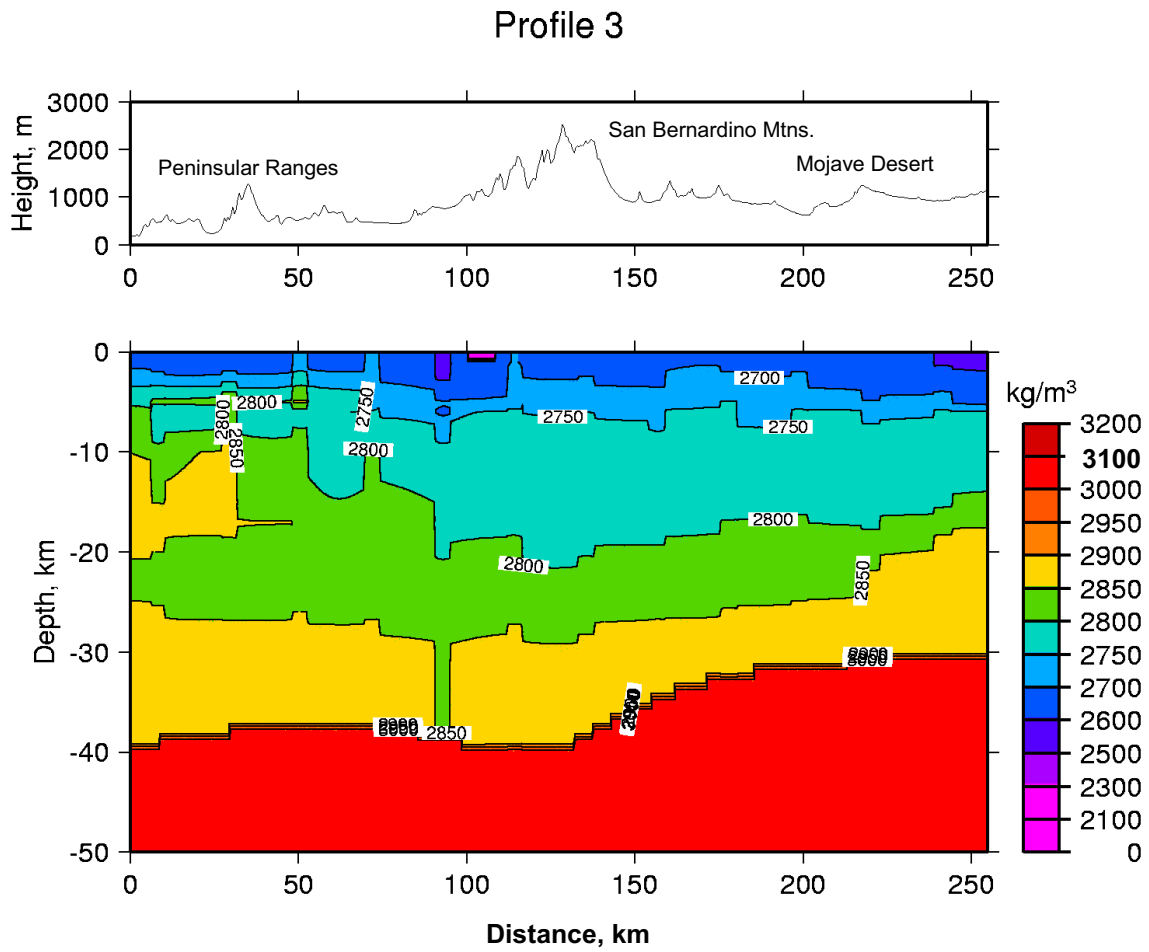


Figure 14 (a). Plot of topography along Profile 3 in Figure 1. (b) Contour plot of densities along Profile 3 inferred from the velocities in Figure 10 using empirical scaling relations between  $V_p$  and density (Magistrale et al., 1996).

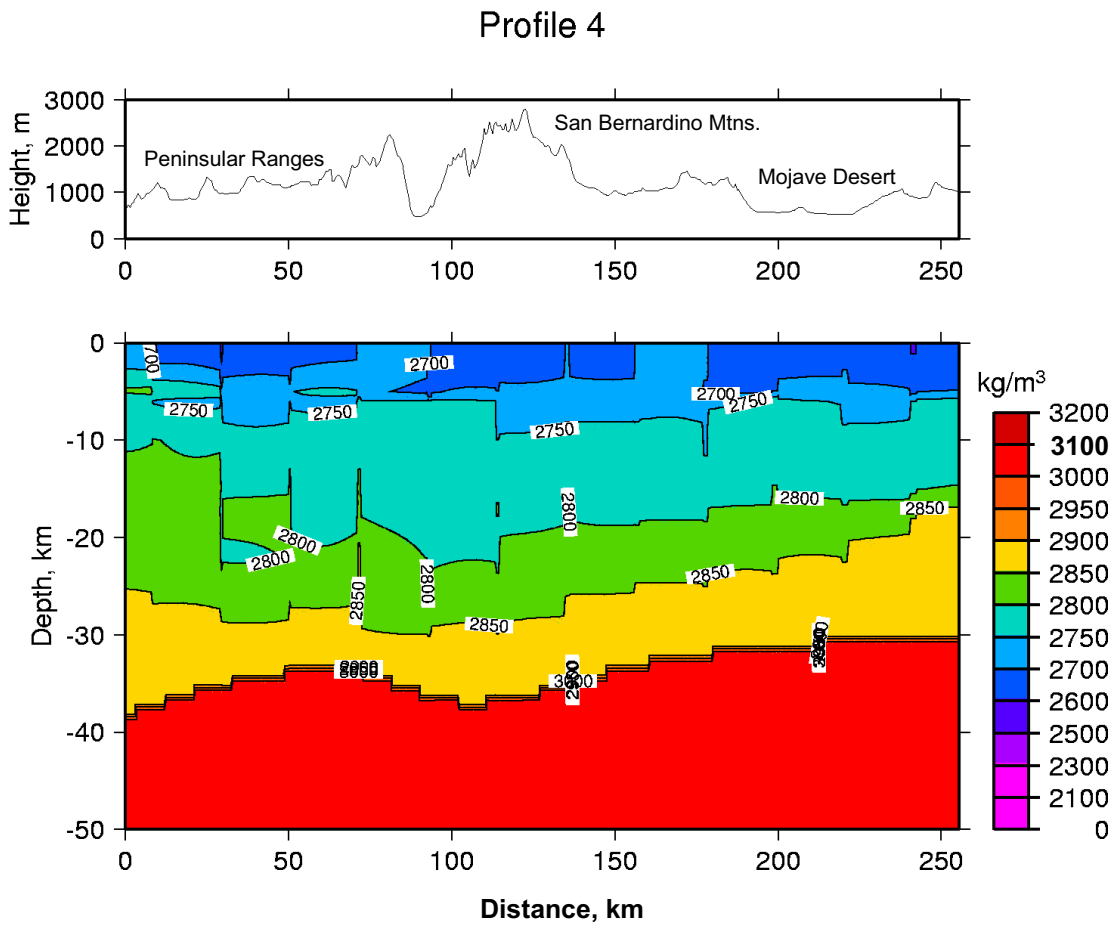


Figure 15 (a). Plot of topography along Profile 4 in Figure 1. (b) Contour plot of densities along Profile 4 inferred from the velocities in Figure 11 using empirical scaling relations between  $V_p$  and density (Magistrale et al., 1996).

## **Gravity Models**

To date, we have completed analysis of one profile only (Profile 2, Figure 1), and present those results here. In order to compare our gravity model with the observed gravity for Profile 2, we extracted the observed gravity from the observed regional Bouguer gravity (Figure 2). In the following gravity models, we tried to maximize the fit to (1) the entire profile, (2) inside the LA Basin, (3) outside the LA Basin and (4) to the Mojave Desert. We solve for the crustal density but keep the mantle density at  $3300 \text{ kg/m}^3$ .

We find that, in general, gravity data and crustal tomographic structures are consistent with each other. However, we find that there are significant misfits in the eastern LA Basin and in the Mojave Desert. We are unable to fit the gravity in Profile 2 very well using a uniform crustal density across the entire profile (Figure 16). We then tried to maximize the fit to the LA Basin (Figure 17). In order to obtain a good fit to the LA Basin we used an average density of  $2756 \text{ kg/m}^3$ . The fit, however, is poor outside the basin particularly in the Mojave Desert. We then looked at maximizing the fit outside the LA Basin (Figure 18). In order to obtain a good fit around the outside of the LA Basin we used an average density of  $2794 \text{ kg/m}^3$  however again the fit is poor in the Mojave Desert. To improve the fit in the Mojave Desert we tried increasing the Moho depth in this region (Figure 19).

The gravity anomaly in the Mojave Desert section of the profile is more negative than predicted, suggesting the presence of a subsurface crustal mass deficit. This region can be well-matched by increasing the depth of the Moho under the Mojave Desert to 34 km and increasing the average densities in the Desert. The Moho structure that best fits the gravity in the Mojave desert is shown in Figure 20. The contour plot of densities along Profile 2 is inferred from the velocities in Figure 9, but with a deeper Moho depth (34 km) in the Mojave Desert.

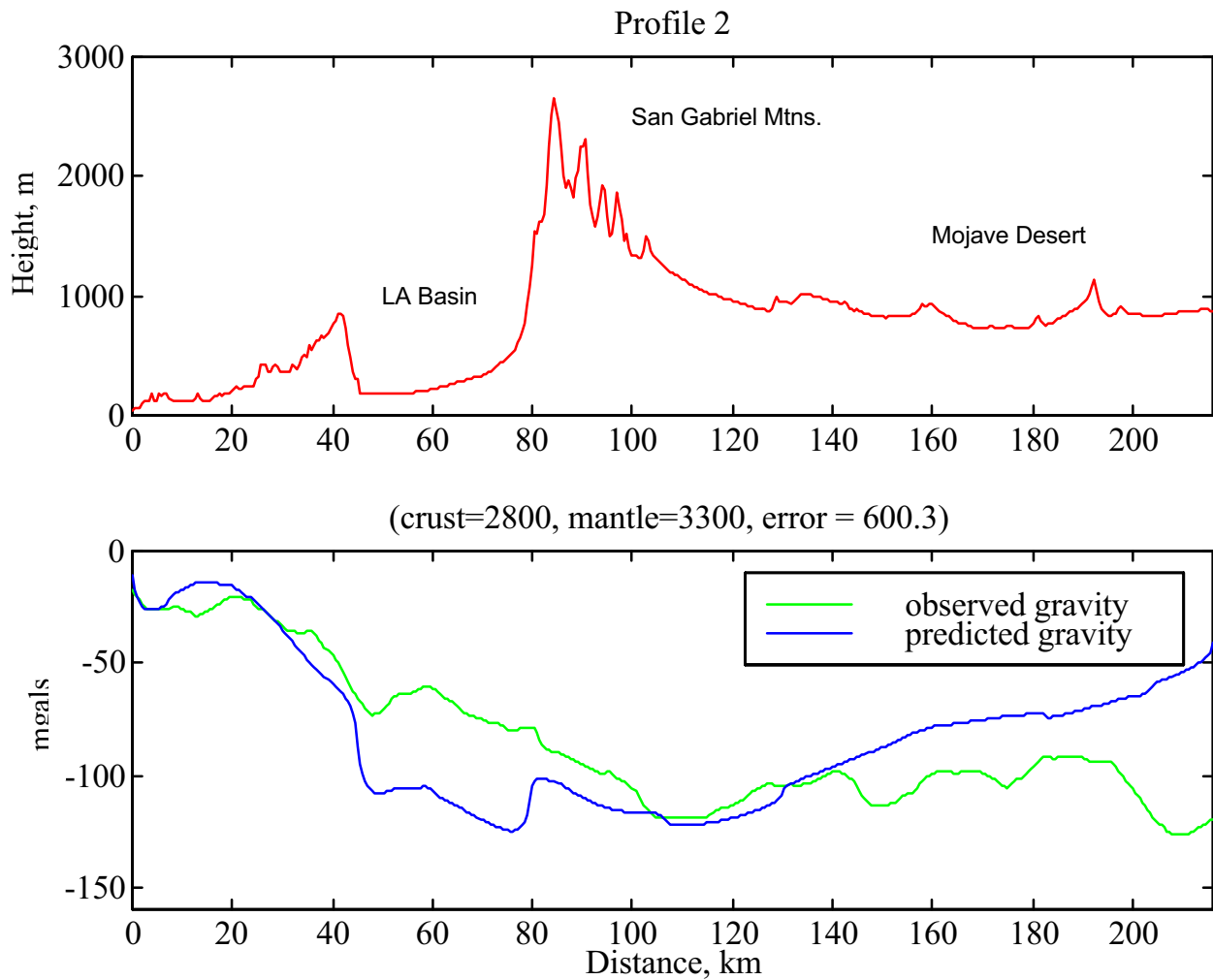


Figure 16 (a): Plot of topography along Profile 2 in Figure 1. (b) Best fit for gravity across the entire profile is obtained with  $\rho_{\text{crust}} = 2800 \text{ kg/m}^3$  and  $\rho_{\text{mantle}} = 3300 \text{ kg/m}^3$ . We are unable to fit the gravity in Profile 2 very well using a uniform crustal density across the entire profile.

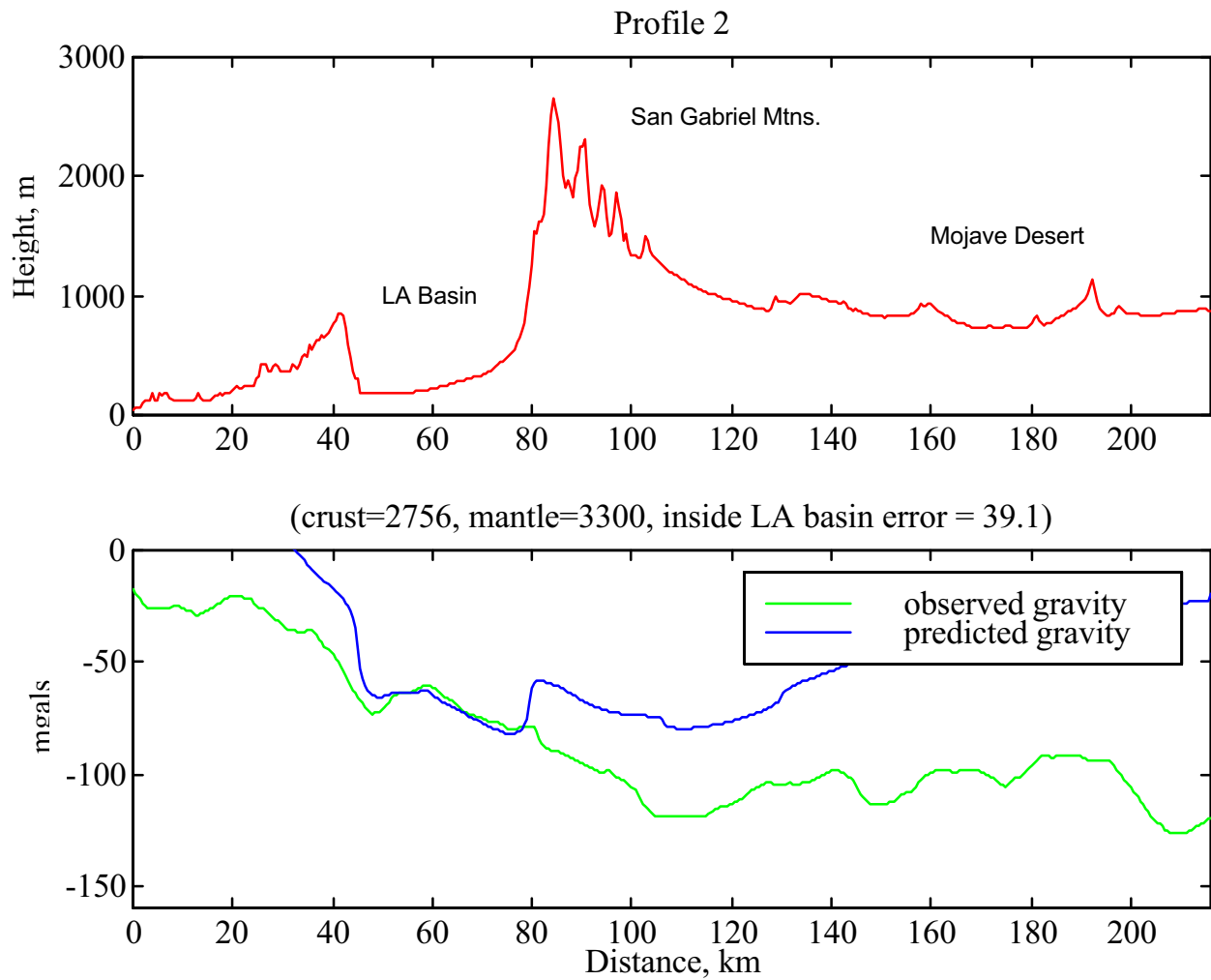


Figure 17 (a): Plot of topography along Profile 2 in Figure 1. (b) Best fit for gravity in the LA Basin is obtained with  $\rho_{\text{crust}} = 2756 \text{ kg/m}^3$  and  $\rho_{\text{mantle}} = 3300 \text{ kg/m}^3$ . The fit is poor outside the basin particularly in the Mojave Desert.

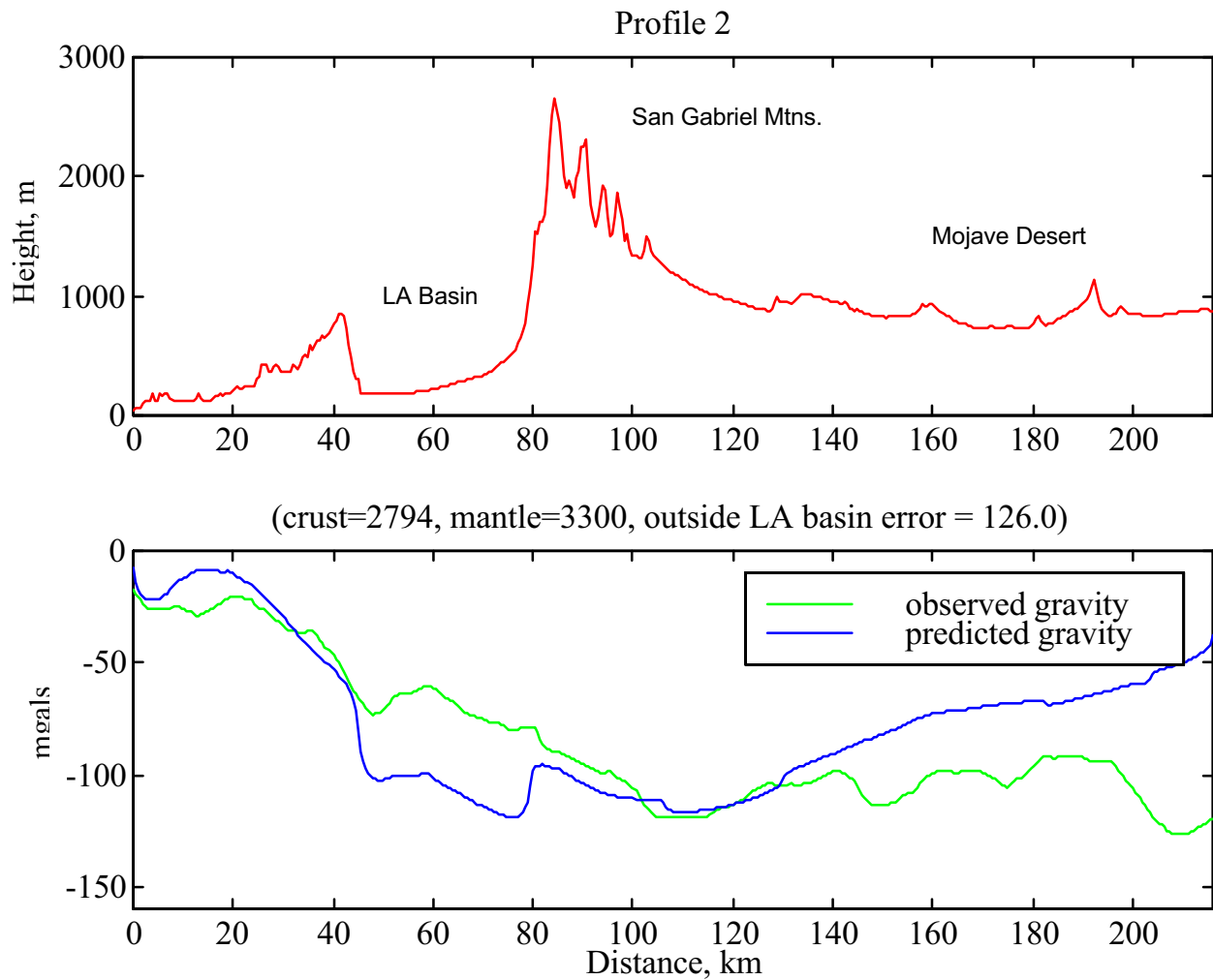


Figure 18 (a). Plot of topography along Profile 2 in Figure 1. (b) Best fit for gravity outside the LA Basin is obtained with  $\rho_{\text{crust}} = 2794 \text{ kg/m}^3$  and  $\rho_{\text{mantle}} = 3300 \text{ kg/m}^3$ . The fits are good outside the LA Basin but not in the Mojave Desert.

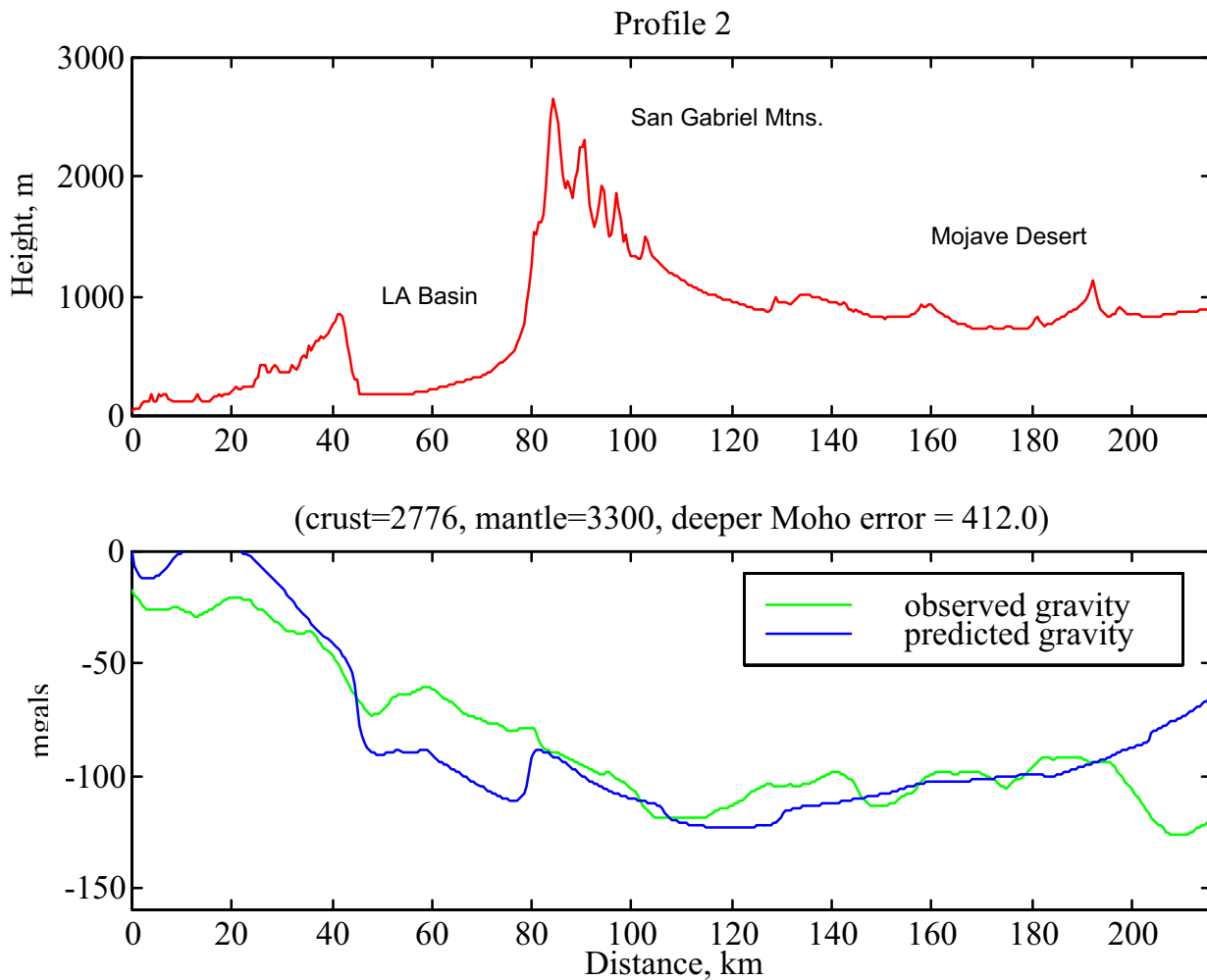


Figure 19 (a). Plot of topography along Profile 2 in Figure 1. (b) Best fit for gravity in the Mojave Desert is obtained with  $\rho_{\text{crust}} = 2776 \text{ kg/m}^3$  and  $\rho_{\text{mantle}} = 3300 \text{ kg/m}^3$ . To improve the fit in the Mojave Desert, we increased the Moho depth in this region.

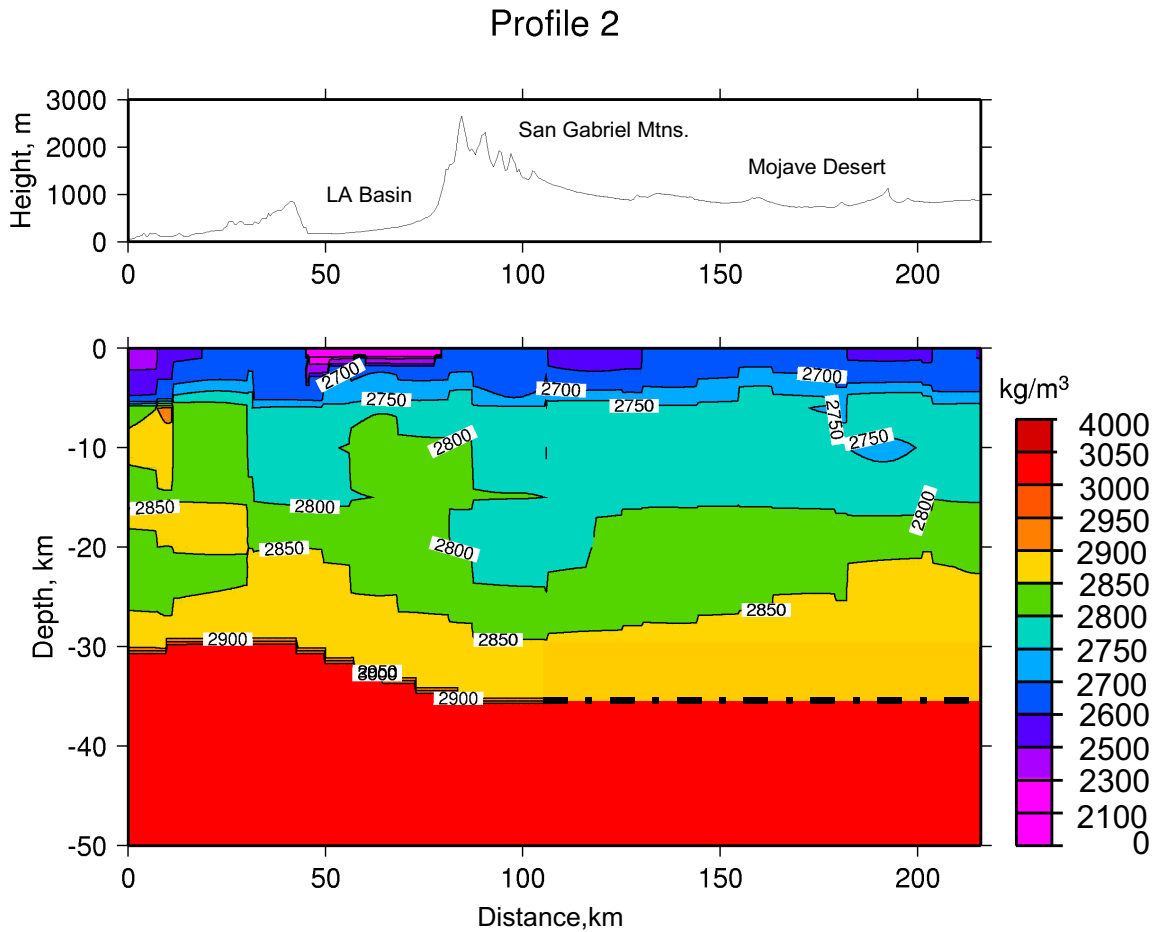


Figure 20 (a). Plot of topography along Profile 2 in Figure 1. (b) The Moho structure that best fits the gravity in the Mojave Desert. Contour plot of densities along Profile 2 inferred from the velocities in Figure 9, but with a deeper Moho depth (2900  $\text{kg/m}^3$  contour above) in the Mojave Desert.

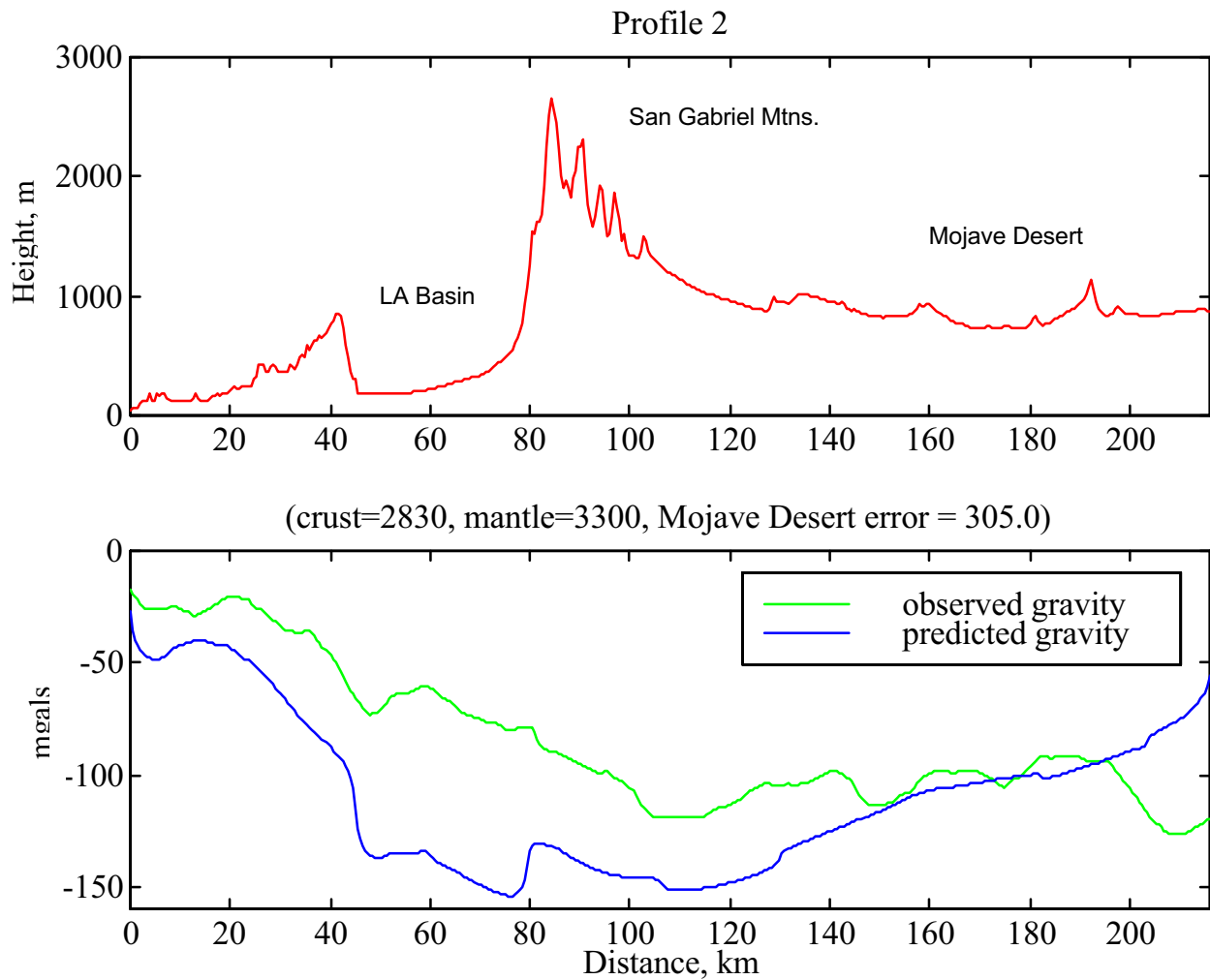


Figure 21 (a). Plot of topography along Profile 2 in Figure 1. (b) Best fit for in the Mojave Desert by increasing the average density of the crust is obtained with  $\rho_{\text{crust}} = 2830 \text{ kg/m}^3$  and  $\rho_{\text{mantle}} = 3300 \text{ kg/m}^3$ .

During the SCEC Annual Meeting in Oxnard, California, we received excellent feedback on our poster from Lupei Zhu and Harold Magistrale on the matter of deepening the Moho in the Mojave Desert in our gravity model. It was suggested that we reduce the crustal density in the Mojave instead of deepening the Moho since the velocity model points to a low velocity zone under the Mojave Desert. We then tried to maximize the fit in the Mojave Desert by reducing the crustal density and our results are shown in Figure 21.

## **CONCLUSION**

We plan to compare predicted gravity along the three other profiles across the central and eastern Transverse Ranges to the observed gravity. Our results so far suggest that, in general, seismic velocities are consistent with gravity in our study area. However, to obtain good fits simultaneously in the LA Basin and outside, we require an increase in average density in the LA Basin, so that the amplitude of the anomaly due to the basin sediments is reduced (Figure 18). Fits to gravity in the Mojave Desert are inadequate in general (Figure 19). The data suggest the presence of crustal mass deficit in the region (either a deeper Moho or reduced average crustal density (Figure 21), Roy and Clayton, 2000). The preliminary results above apply to Profile 2, and should not be generalized to the other profiles until we have completed our analysis.

## **ACKNOWLEDGEMENTS**

We are grateful to the Southern California Earthquake Center for supporting this work. We thank Shawn Biehler, UC Riverside, for providing a large regional data set of free air and complete Bouguer anomalies and Harold Magistrale for access to the SCEC 3D velocity model. We also thank Harold Magistrale, SDSU and Robert Clayton, Caltech, for discussions.

## BIBLIOGRAPHY

- Atwater, T., Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, 81, 3515-3535, 1970.
- Clayton, R., 3D Velocity Model for Southern California, <http://www.scecdc.org/3Dvelocity/3Dvelocity.html>, 1997.
- Fowler, C.M.R., The Solid Earth: An Introduction to Global Geophysics, Cambridge University Press, 472 p., 1990.
- Langenheim, V.E., and R.C. Jachens, Gravity data collected along the Los Angeles Regional Seismic Experiment (LARSE) and preliminary model of regional density variations in basement rocks, Southern California, USGS Open-File Report 96-682, 1996.
- Magistrale, H., Day, S., Clayton, R. and R. Graves, The SCEC Southern California 3D Seismic Velocity Model Version 2, BSSA (in preparation).
- Magistrale, H., McLaughlin, K., and S. Day, A geology-based 3D velocity model of the Los Angeles basin sediments, BSSA, 86, 1161-1161, 1996.
- Roy, M. and R. Clayton, submitted to JGR, 2000.
- Talwani, M., Worzel, J.L., and Landisman, M., Rapid Gravity Computations for Two-Dimensional bodies with application to the Mendocino Submarine Fracture Zone, J. of Geophys. Res., v. 64, 49-59, 1959.

## *Nancy Helen Natek*

Current Address  
10401 Camino Del Oso NE  
Albuquerque, New Mexico 87111  
(505) 271-8792

E-mail Address  
natek@unm.edu

---

- Objective** Continue my pursuits to attain an advanced degree in Geophysics in the fields of Seismic Tomography, Velocity and/or Gravity Modeling.
- Education** **The University of New Mexico**, Bachelor of Science, Geology, Structural/ Tectonics/Geophysics Track, Cumulative GPA 3.761/4.000, Geology GPA 3.890/4.000. Expected graduation date: May 2001.
- Selected Upper Level Coursework** Geophysics  
Statistics and Data Analysis in Earth Science  
Advanced Field Geology  
Strength and Dynamics of the Lithosphere  
Processes in the Earth's Deep Interior  
Alpine and Himalayan Tectonics  
Regional Tectonics  
Geologic Presentation  
Technical Writing
- Computational Experience** UNIX: Sun Sparcstation, NeXtstation  
Macintosh/Windows NT/NeXtstep  
GIS Arcinfo and Arcview  
General Mapping Tools (GMT)  
Mathematica, Matlab, HTML  
TeX, LaTeX, Scientific Word
- Academic Honors and Scholarships** **University of New Mexico**, Earth & Planetary Sciences, Sherman A. Wengerd Outstanding Junior Award, May 2000.  
**University of New Mexico**, Earth & Planetary Sciences, General Thomas Campbell Award, May 2000.  
**New Mexico Geological Society**, Lucille Pipkin Undergraduate Award, April 2000.  
**Albuquerque Gem and Mineral Club**, Undergraduate Scholarship, December 1999.  
**University of New Mexico**, College of Arts and Sciences, Semester Honor Roll, Fall 1999.  
**New Mexico Geological Society**, Lucille Pipkin Undergraduate Award, May 1999.  
**University of New Mexico**, Earth & Planetary Sciences, Harry & Mabel Leonard Scholarship, April 1999.  
**University of New Mexico**, Earth & Planetary Sciences, Harry & Mabel Leonard Scholarship, May 1998.
- Research Experience** **Southern California Earthquake Center**, University of Southern California, Los Angeles, California  
5/00 – 9/00 Research Intern  
SCEC funded award, "Constraints on the Southern California Earthquake Center (SCEC) 3D Velocity Model Based on Gravity Data: 2D Gravity Modeling of the Central and Eastern Transverse Ranges in the Los Angeles Region." Mentor: Dr. Mousumi Roy at the University of New Mexico.  
2D Gravity modeling using General Mapping Tools (GMT) and Matlab

8/99 – 5/00 **The University of New Mexico**, Dept. of Earth & Planetary Sciences, Albuquerque, New Mexico  
Research Assistant  
NSF funded grant, "Geodynamic Response to Extension in Convergent Orogens." PI Dr. Frank Pazzaglia,  
Co-PIs Dr. Mousumi Roy and Dr. Jane Selverstone.  
Input field structural data from the Swiss and Italian Alpine region into ARC/INFO format for GIS spatial  
analyses.

3/99 – 9/99 **The University of New Mexico**, Dept. of Earth and Planetary Sciences, Albuquerque, New Mexico  
Laboratory Assistant  
Dr. John Geissman.  
Preparation of paleomag materials, operation of magnetometers and thermal demagnetometers.

**Additional work experience available on request**

**Conference Presentations** Constraints on the Southern California Earthquake Center (SCEC) 3D Velocity Model: 2D Gravity Modeling of the Central and Eastern Transverse Ranges in the Los Angeles Region with Mousumi Roy, Annual Meeting of the Southern California Earthquake Center, Oxnard, California, September 2000.

**Affiliations** Member, Geological Society of America, Structural Geology and Tectonics Division  
Member, American Geophysical Union, Tectonophysics and Seismology Sections  
Member, Society of Exploration Geophysicists  
Member, Golden Key National Honor Society

**Languages** French