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

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

Advisor
Dr. Mousumi Roy

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Research sponsored by
Southern California Earthquake Center

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ILLUSTRATIONS

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

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) Vp and Vs 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 Vp 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.

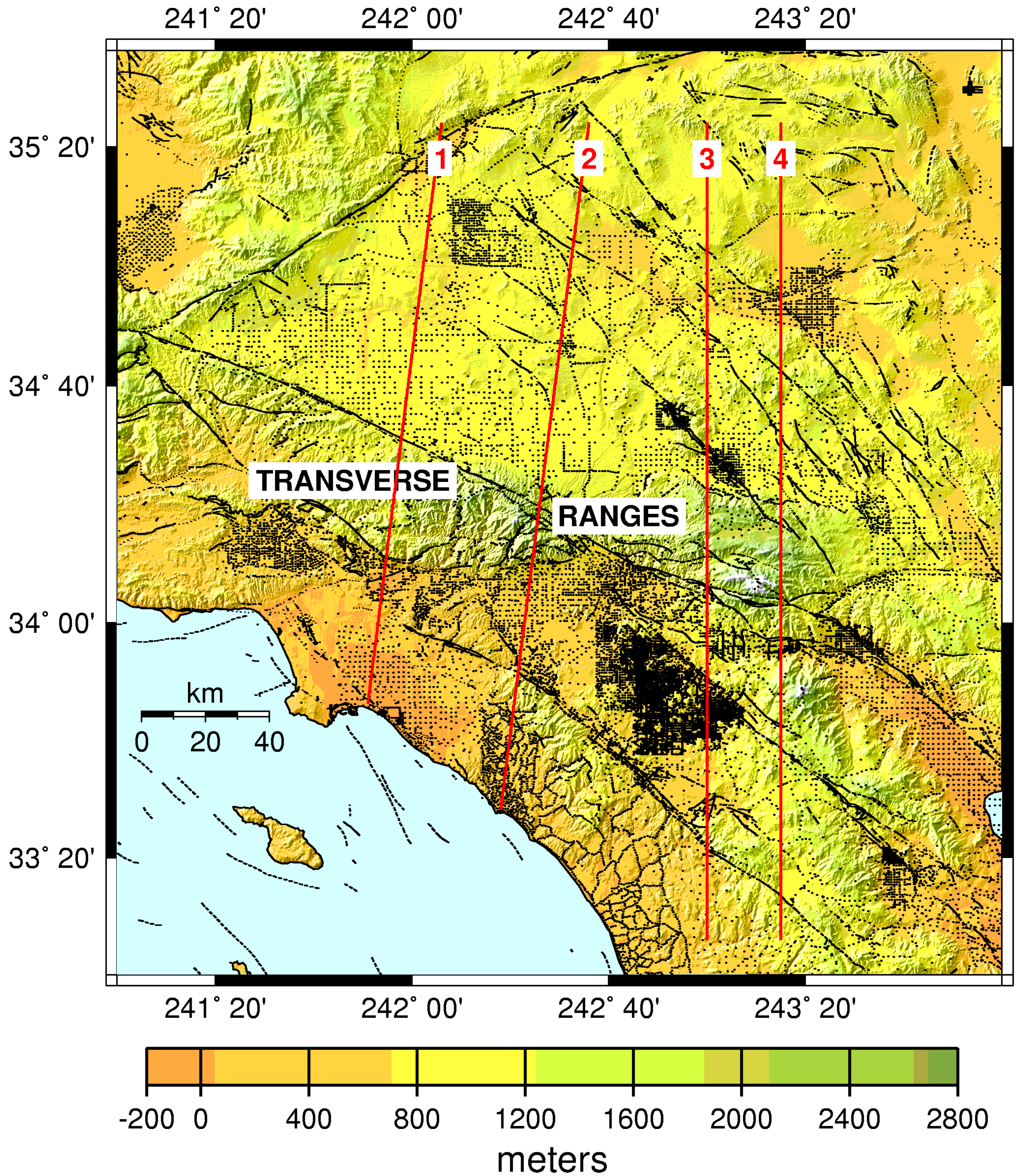

Figure 1. Shaded relief for the study area, with lines showing locations of our four gravity model profiles. Solid black dots represent locations at which the Bouguer gravity anomaly is measured.

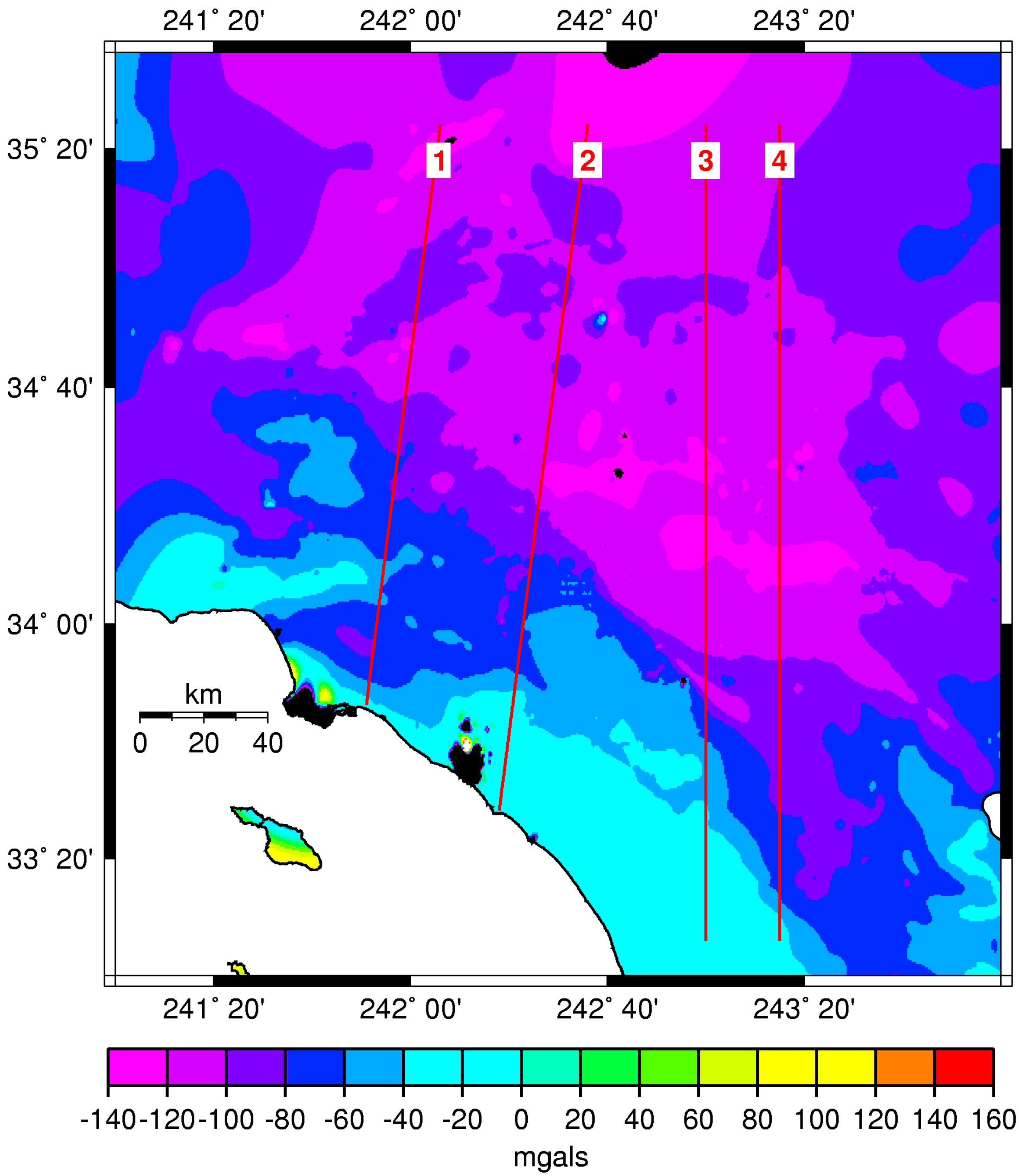

Figure 2. The Bouguer gravity for the study area is obtained from a regional data set of southern California gravity from Professor S. Biehler at UC Riverside.

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 ρ_c = average density of the crust and ρ_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^3 and an average mantle density of 3300 kg/m^3 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 Vp and density (Magistrale et al., 1996) and are shown in Figures 12, 13, 14, and 15. The density structures > 2700 kg/ m^3 are contoured at 50 kg/m^3 intervals.

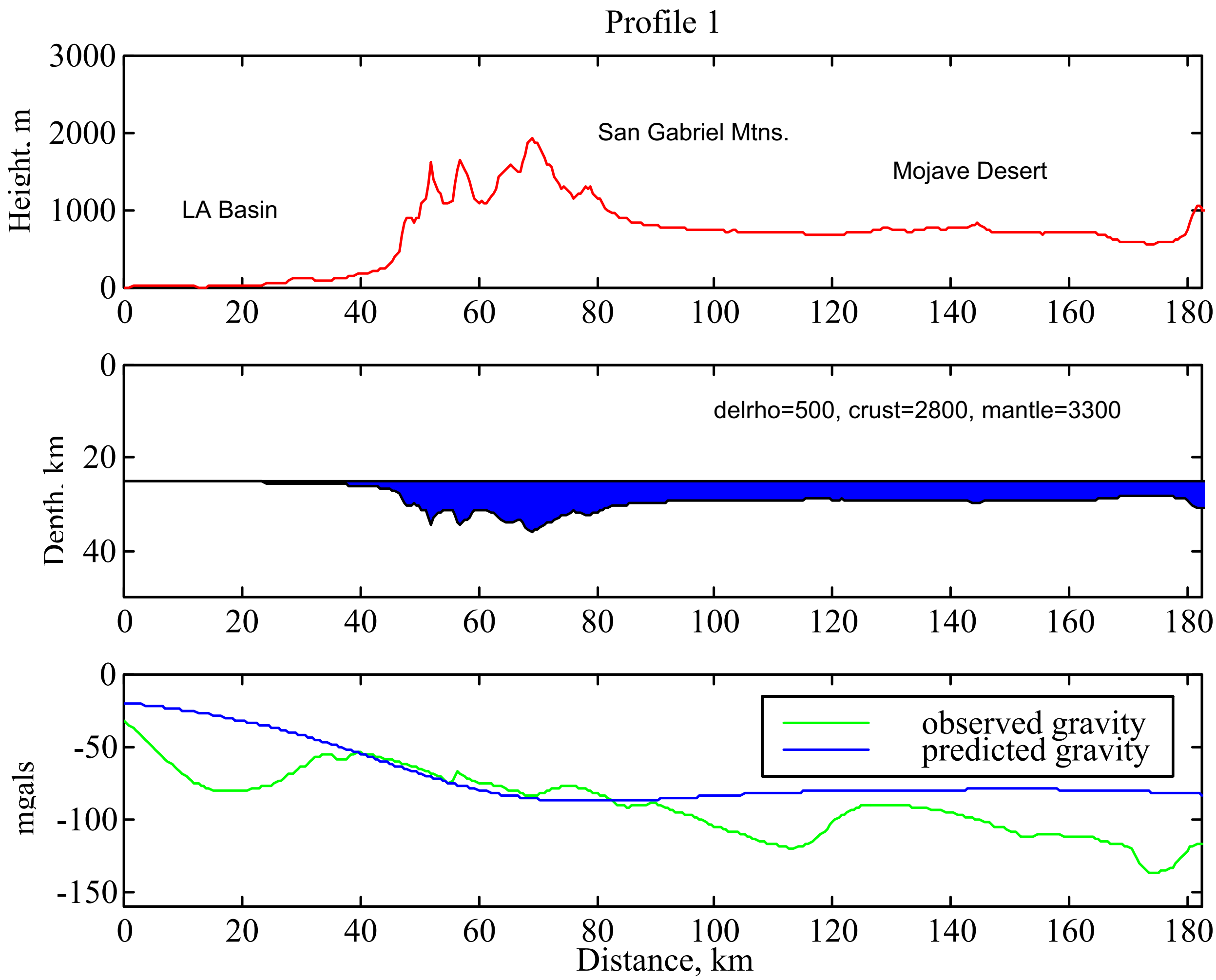

Figure 3(a): Plot of topography along Profile 1 in Figure 1. (b) Airy compensation model. (c) Predicted gravity along Profile 1 with ρ_{crust} = 2800 kg/m^3 and ρ_{mantle} = 3300 kg/m^3 using the Talwani method (Talwani, 1959).

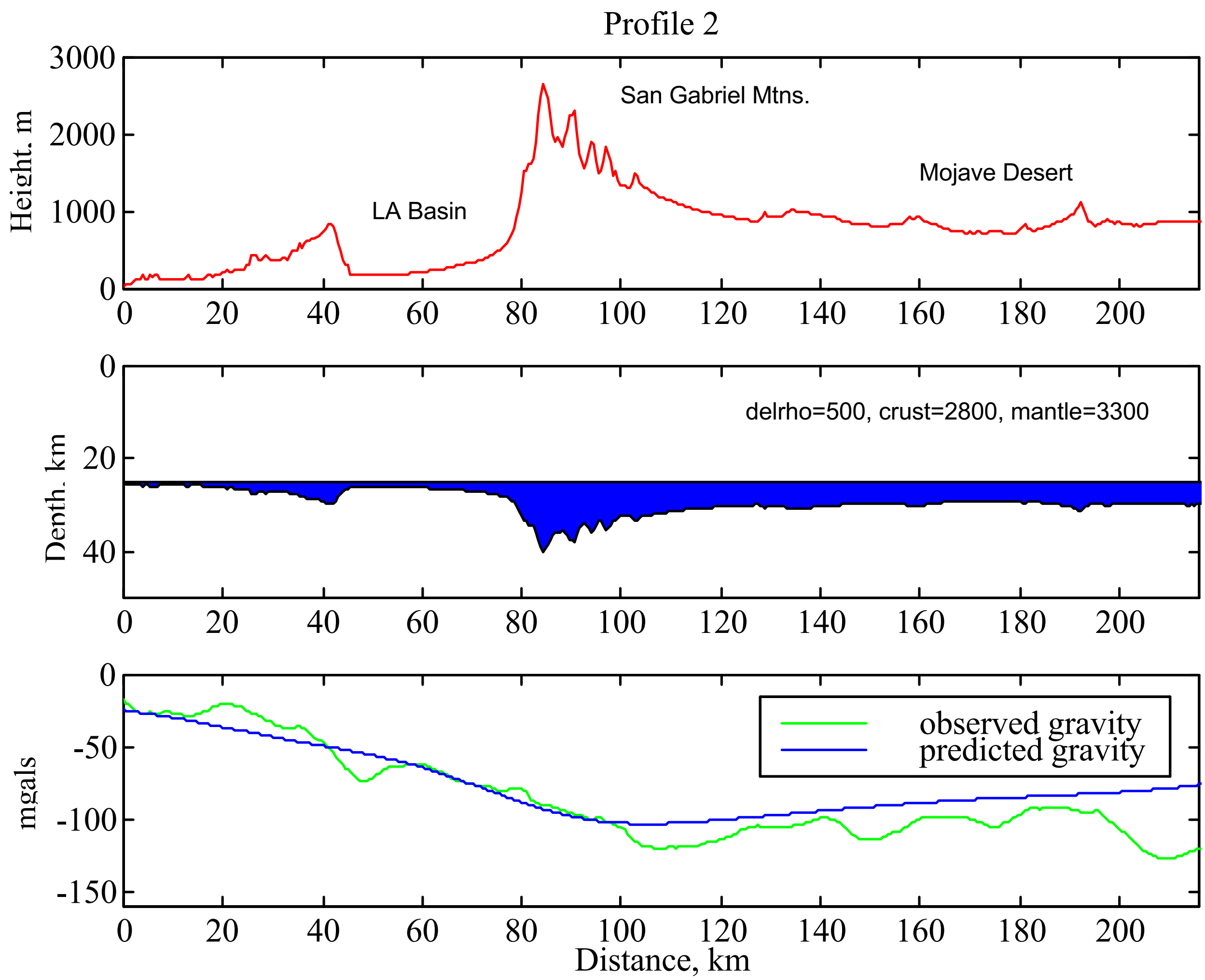

Figure 4(a): Plot of topography along Profile 2 in Figure 1. (b) Airy compensation model. (c) Predicted gravity along Profile 2 with ρ_{crust} = 2800 kg/m^3 and ρ_{mantle} = 3300 kg/m^3 using the Talwani method (Talwani, 1959).

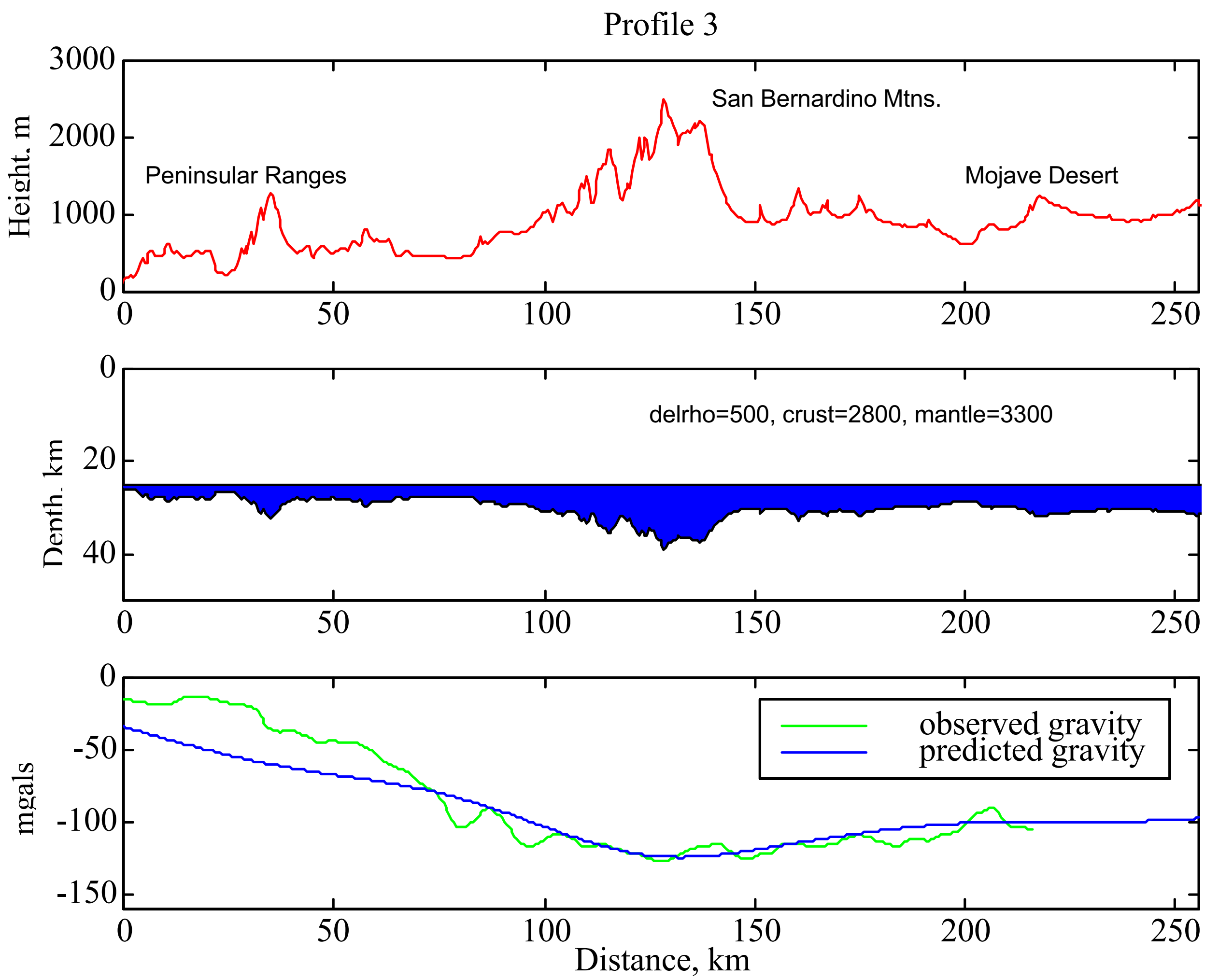

Figure 5(a): Plot of topography along Profile 3 in Figure 1. (b) Airy compensation model. (c) Predicted gravity along Profile 3 with $\rho_{crust} = 2800$ kg/m^3 and $\rho_{mantle} = 3300$ kg/m^3 using the Talwani method (Talwani, 1959).

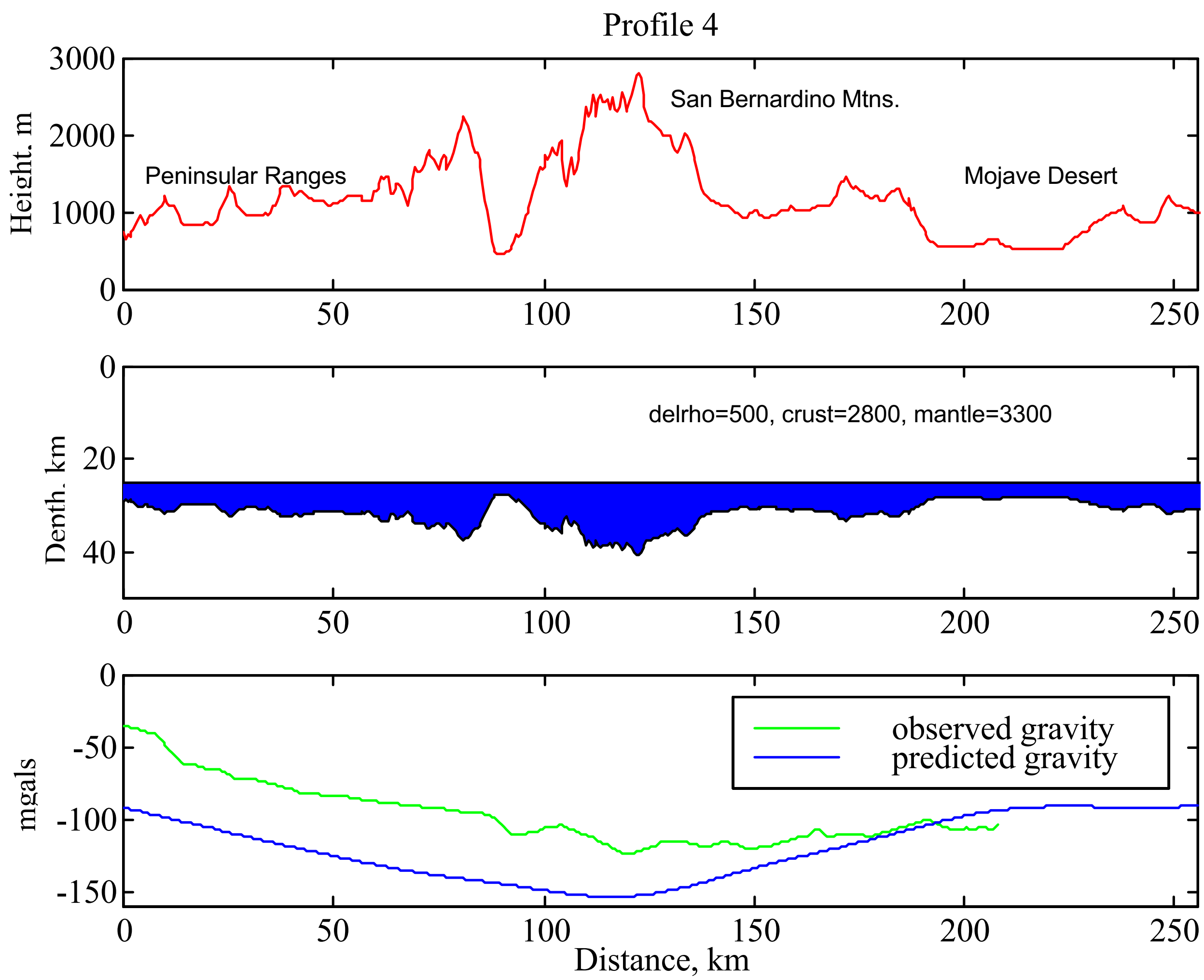

Figure 6(a): Plot of topography along Profile 4 in Figure 1. (b) Airy compensation model. (c) Predicted gravity along Profile 4 with $\rho_{crust} = 2800$ kg/m^3 and $\rho_{mantle} = 3300$ kg/m^3 using the Talwani method (Talwani, 1959).

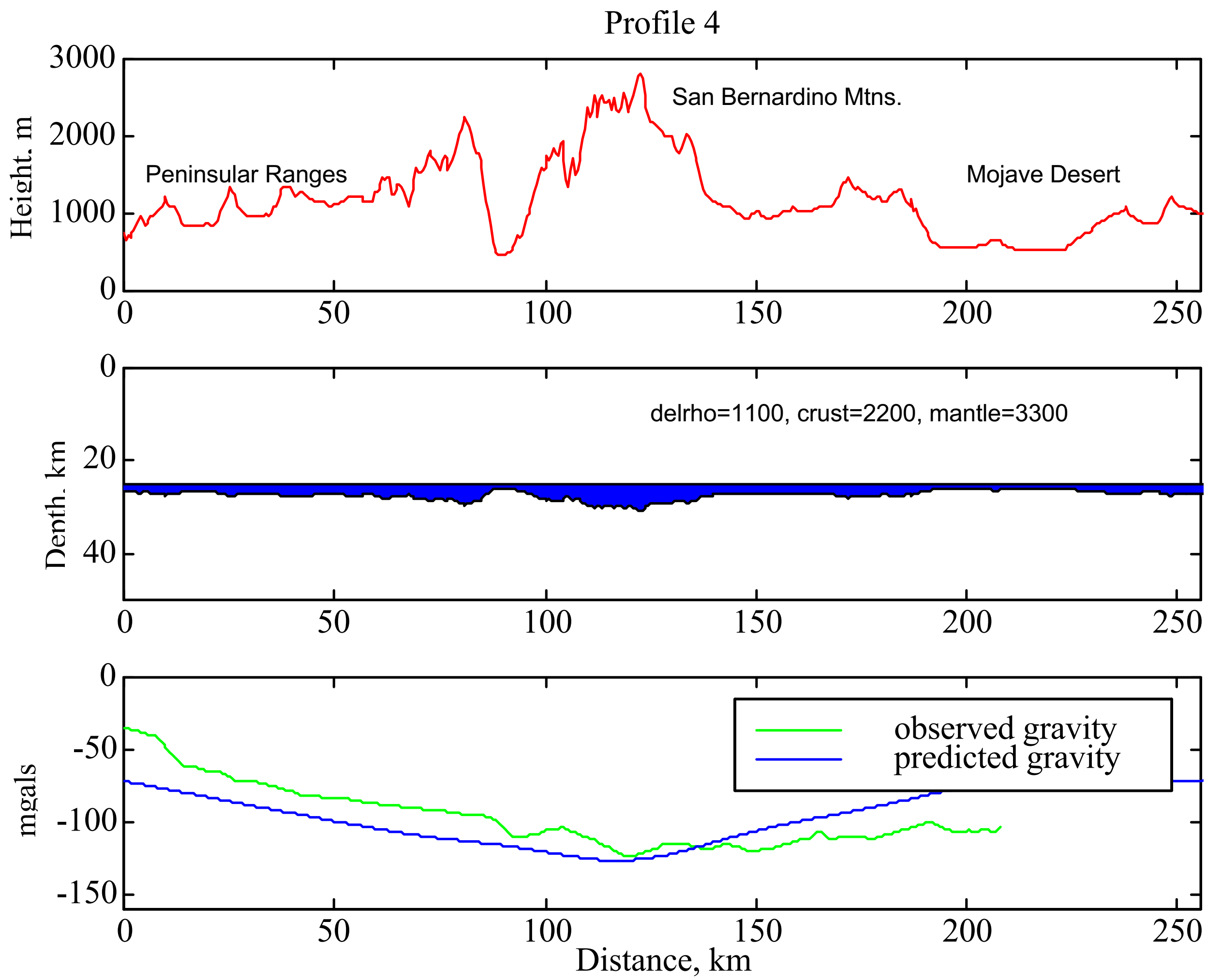

Figure 7(a): Plot of topography along Profile 4 in Figure 1. (b) Airy compensation model. (c) Predicted gravity along Profile 4 with ρ_{crust} = 2200 kg/m^3 and ρ_{mantle} = 3300 kg/m^3 using the Talwani method (Talwani, 1959).

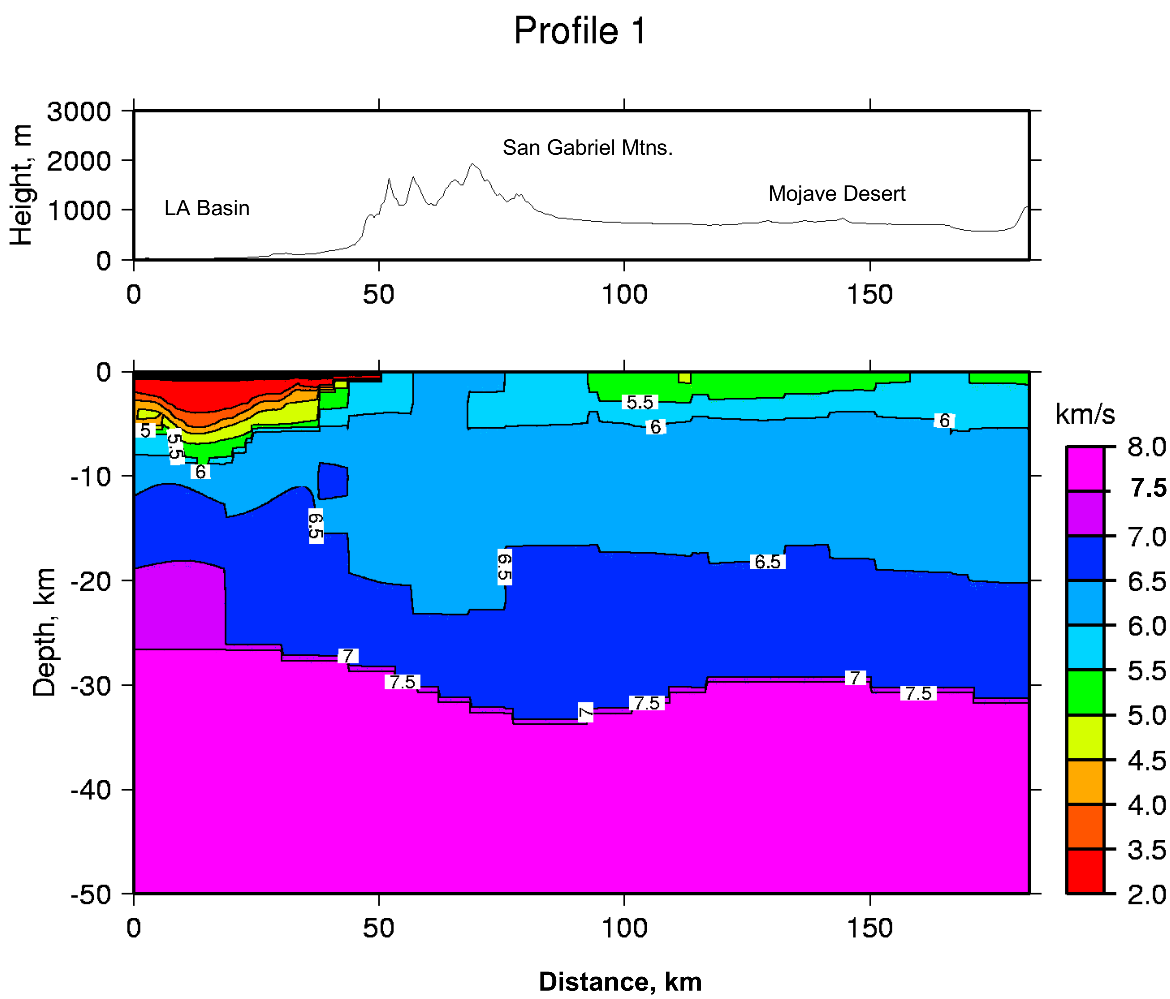

Figure 8 (a). Plot of topography along Profile 1 in Figure 1. (b) Contour plot of p-wave velocities along Profile 1 (Figure 1) from the SCEC 3D velocity model, version 2 (Magistrale et al., in preparation).

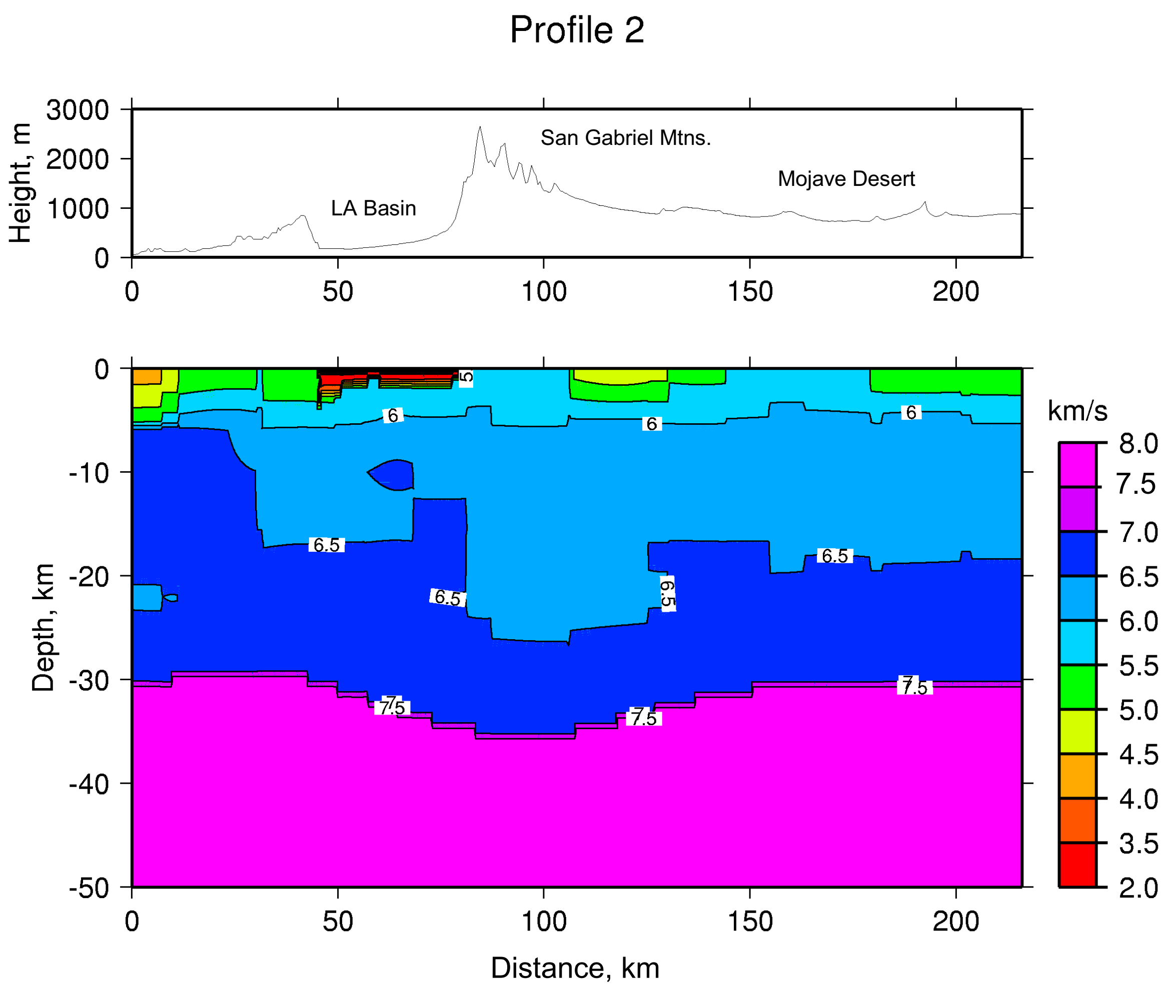

Figure 9 (a). Plot of topography along Profile 2 in Figure 1. (b) Contour plot of p-wave velocities along Profile 2 (Figure 1) from the SCEC 3D velocity model, version 2 (Magistrale et al., in preparation).

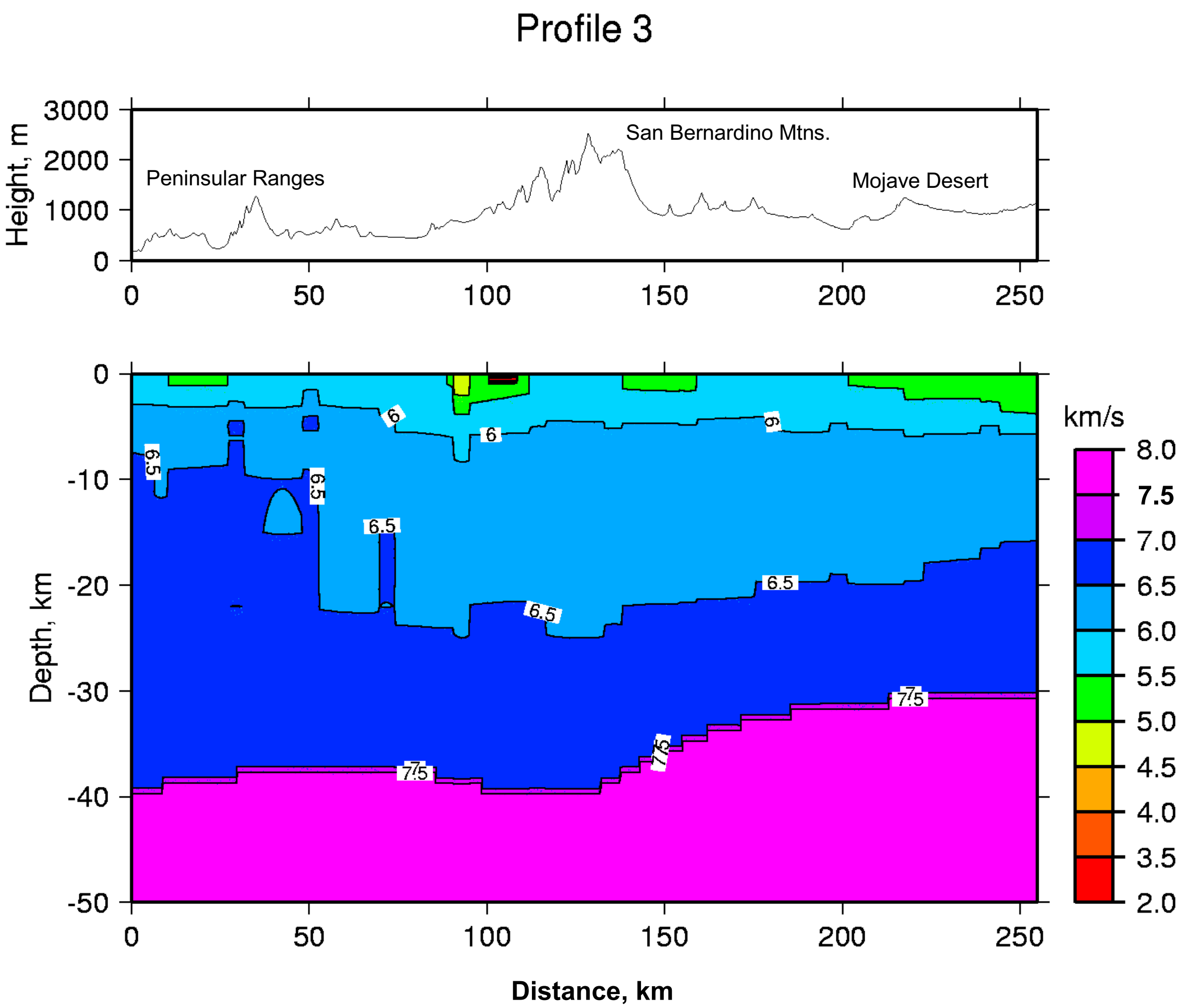

Figure 10 (a). Plot of topography along Profile 3 in Figure 1. (b) Contour plot of p-wave velocities along Profile 3 (Figure 1) from the SCEC 3D velocity model, version 2 (Magistrale et al., in preparation).

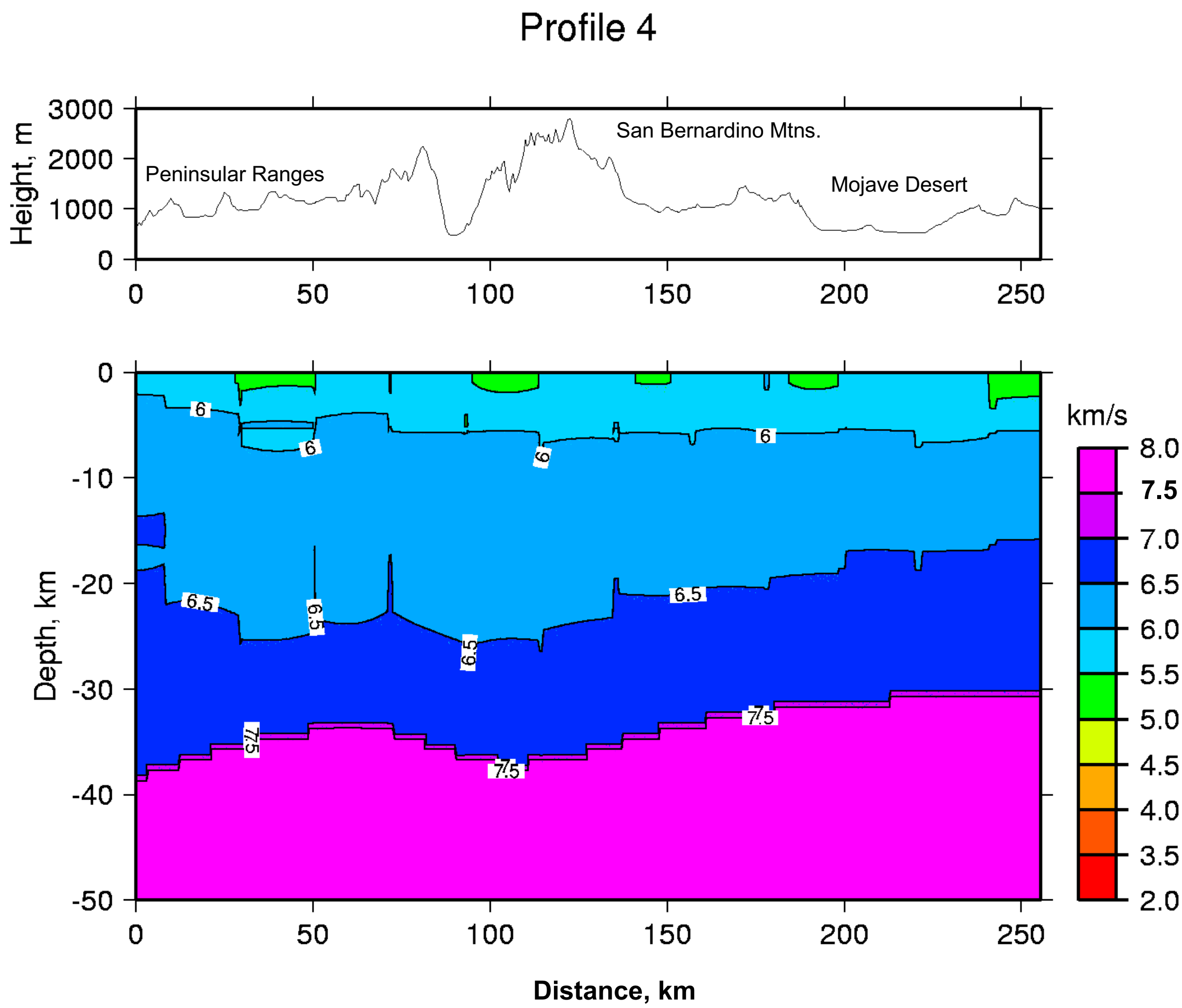

Figure 11 (a). Plot of topography along Profile 4 in Figure 1. (b) Contour plot of p-wave velocities along Profile 4 (Figure 1) from the SCEC 3D velocity model, version 2 (Magistrale et al., in preparation).

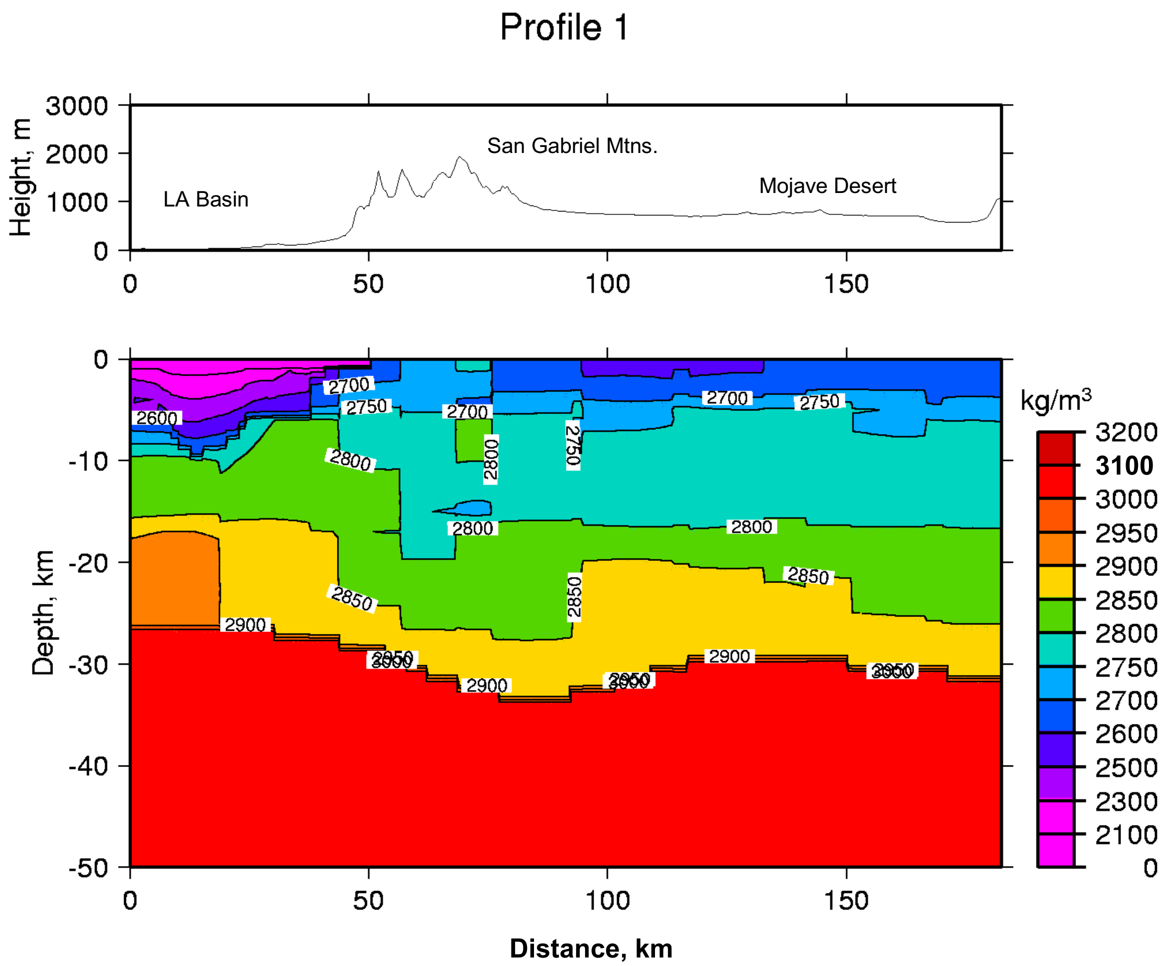

Figure 12 (a). Plot of topography along Profile 1 in Figure 1. (b) Contour plot of densities along Profile 1 inferred from the velocities in Figure 8 using empirical scaling relations between Vp and density (Magistrale et al., 1996).

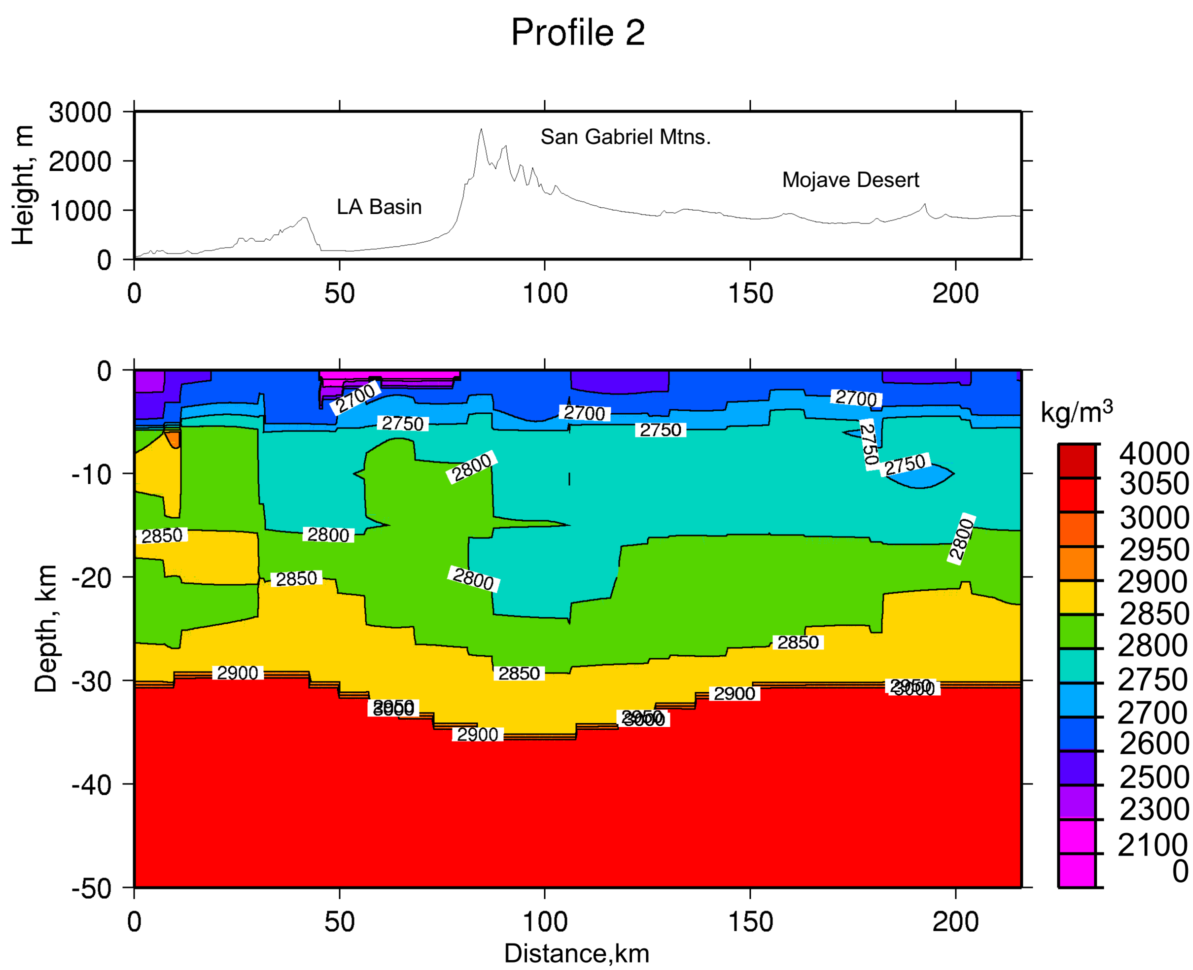

Figure 13 (a). Plot of topography along Profile 2 in Figure 1. (b) Contour plot of densities along Profile 2 inferred from the velocities in Figure 9 using empirical scaling relations between Vp and density (Magistrale et al., 1996).

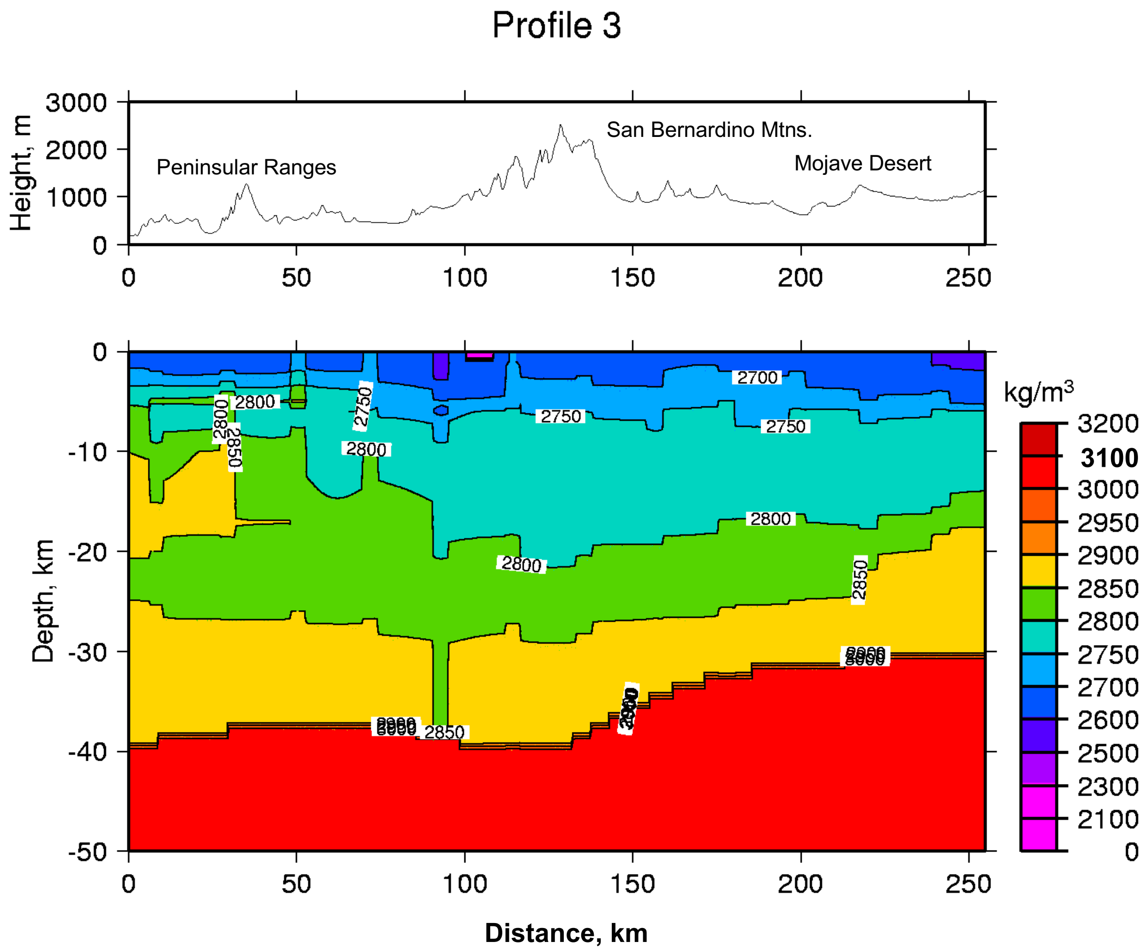

Figure 14 (a). Plot of topography along Profile 3 in Figure 1. (b) Contour plot of densities along Profile 3 inferred from the velocities in Figure 10 using empirical scaling relations between Vp and density (Magistrale et al., 1996).

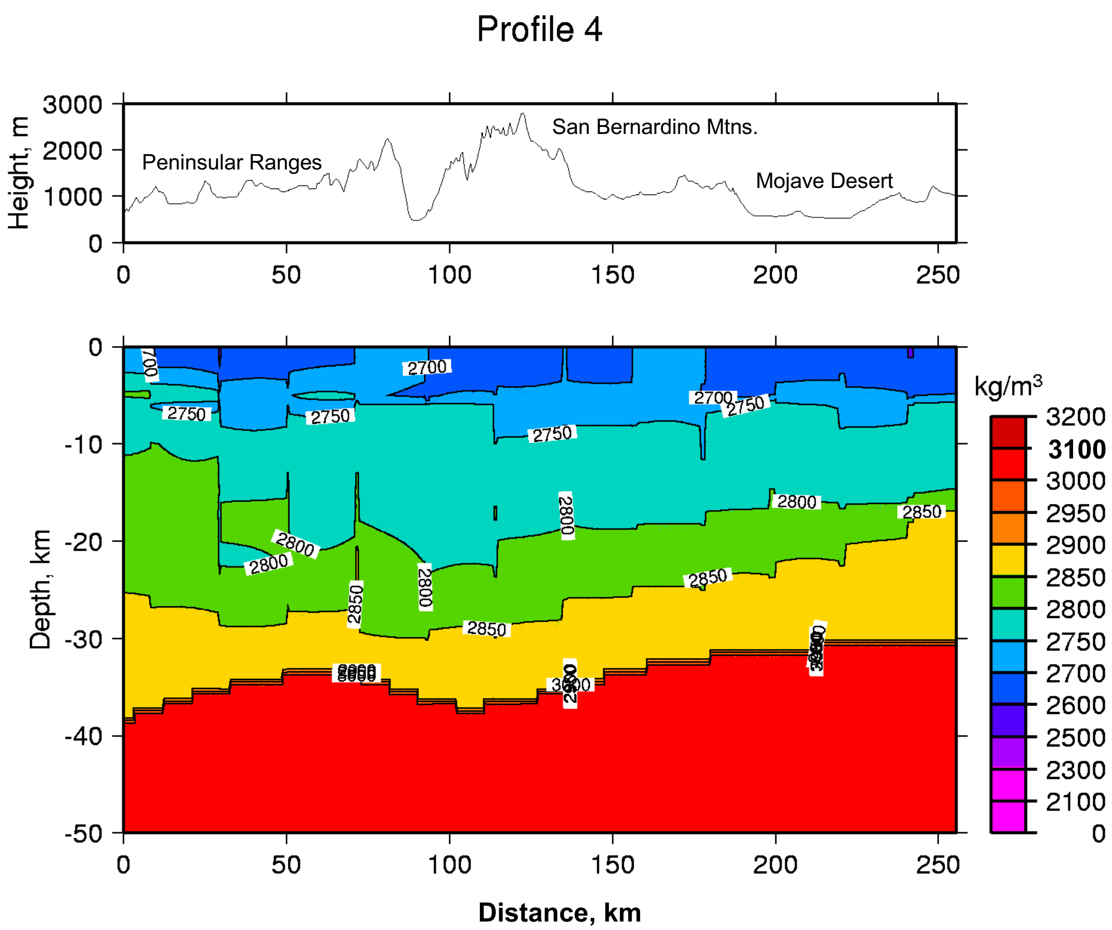

Figure 15 (a). Plot of topography along Profile 4 in Figure 1. (b) Contour plot of densities along Profile 4 inferred from the velocities in Figure 11 using empirical scaling relations between Vp and density (Magistrale et al., 1996).

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 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 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 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 dessert 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.

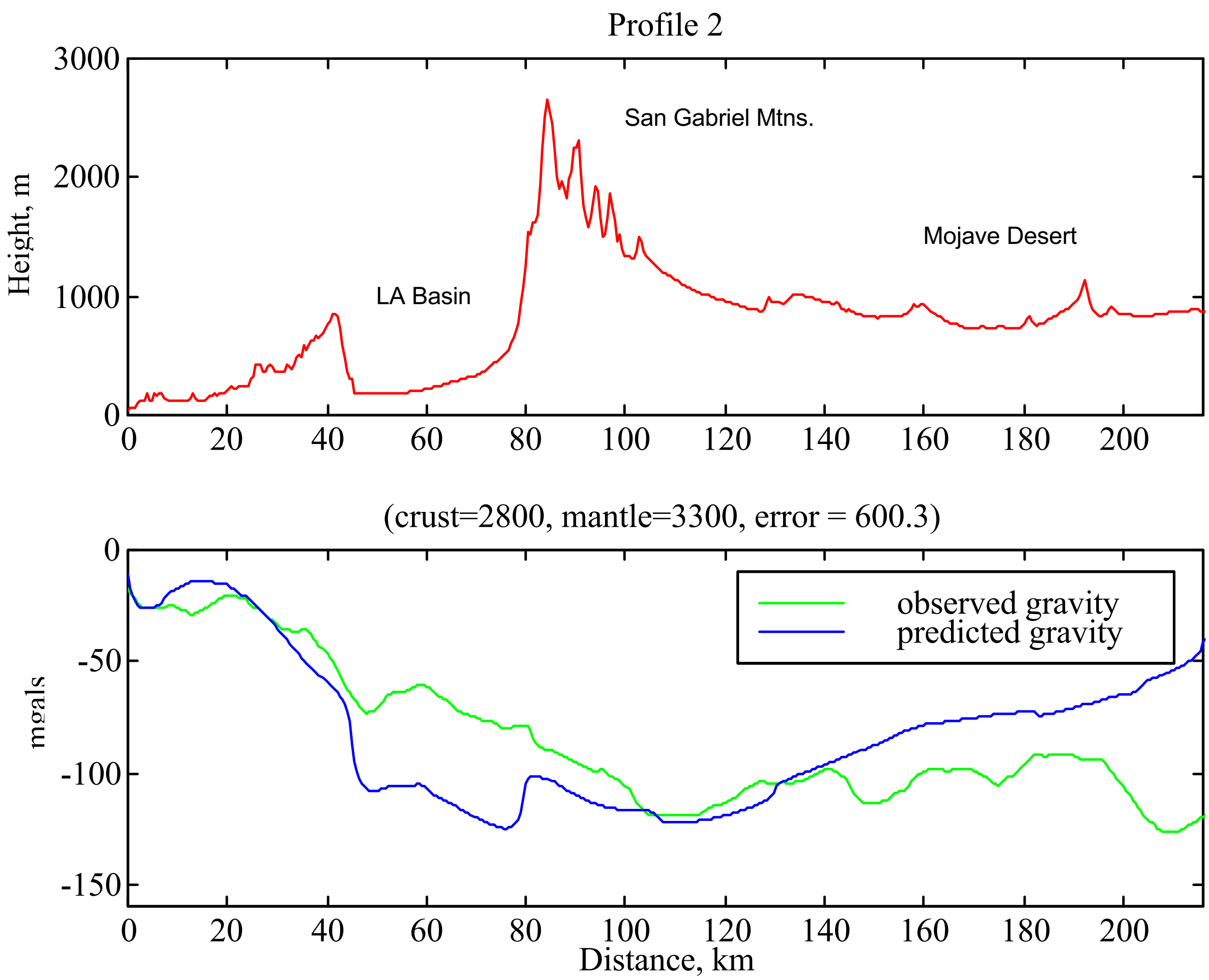

Figure 16 (a): Plot of topography along Profile 2 in Figure 1. (b) Best fit for gravity across the entire profile is obtained with $\rho_{crust} = 2800\ kg/m^3$ and $\rho_{mantle} = 3300\ kg/m^3$. We are unable to fit the gravity in Profile 2 very well using a uniform crustal density across the entire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

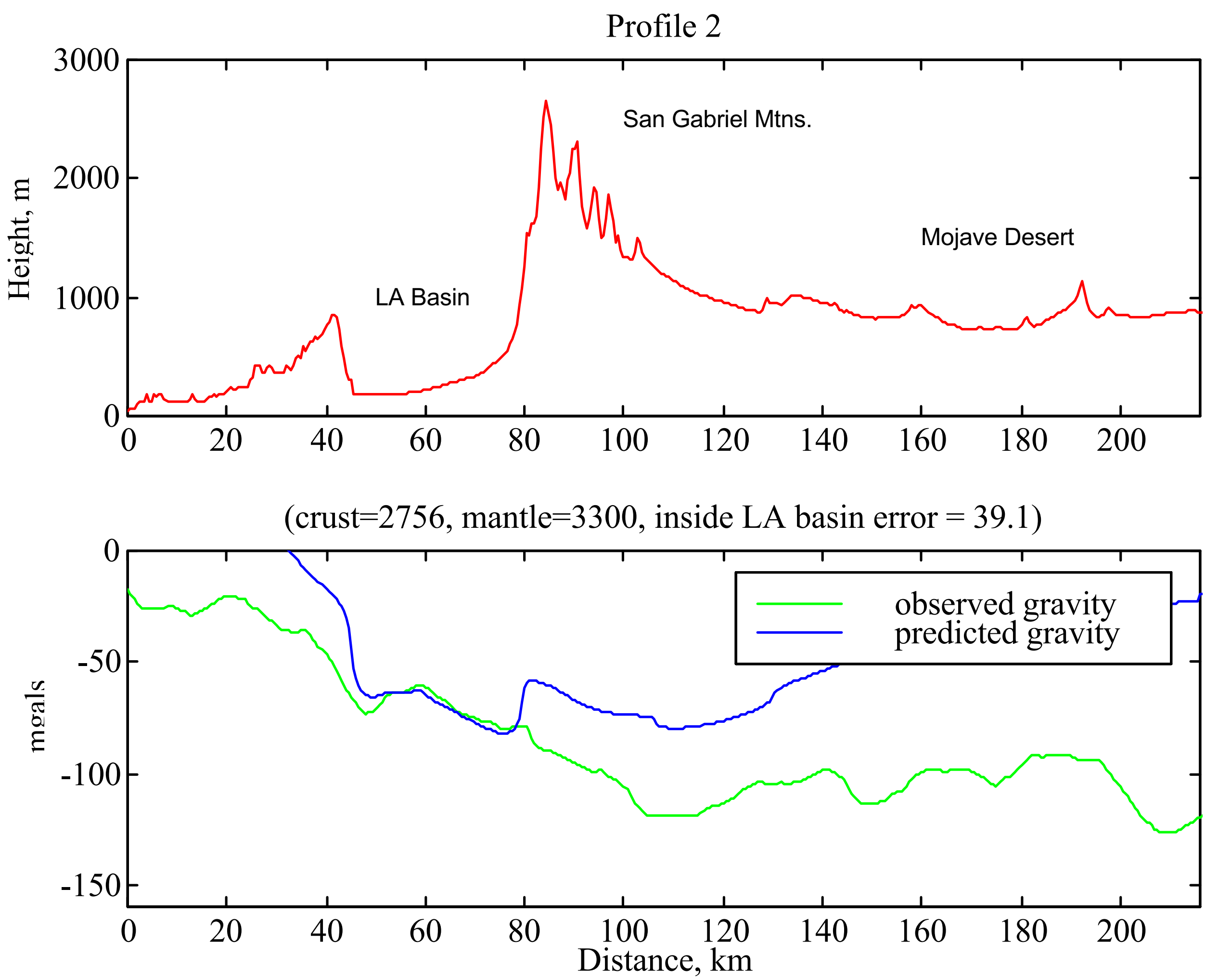

Figure 17 (a): Plot of topography along Profile 2 in Figure 1. (b) Best fit for gravity in the LA Basin is obtained with $\rho_{crust} = 2756$ kg/m^3 and $\rho_{mantle} = 3300$ kg/m^3. The fit is poor outside the basin particularly in the Mojave Desert.

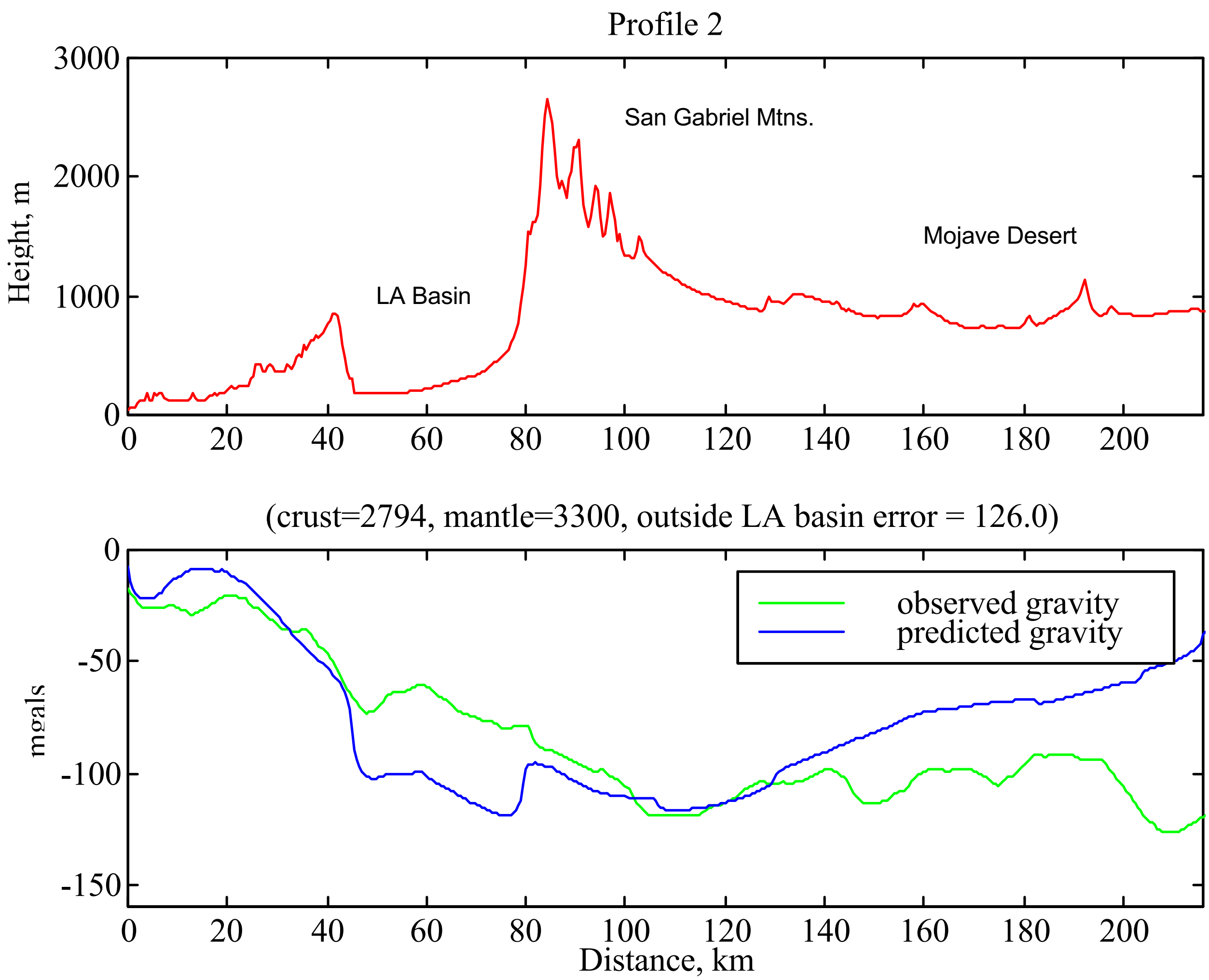

Figure 18 (a). Plot of topography along Profile 2 in Figure 1. (b) Best fit for gravity outside the LA Basin is obtained with $\rho_{crust} = 2794$ kg/m^3 and $\rho_{mantle} = 3300$ kg/m^3. The fits are good outside the LA Basin but not in the Mojave Desert.

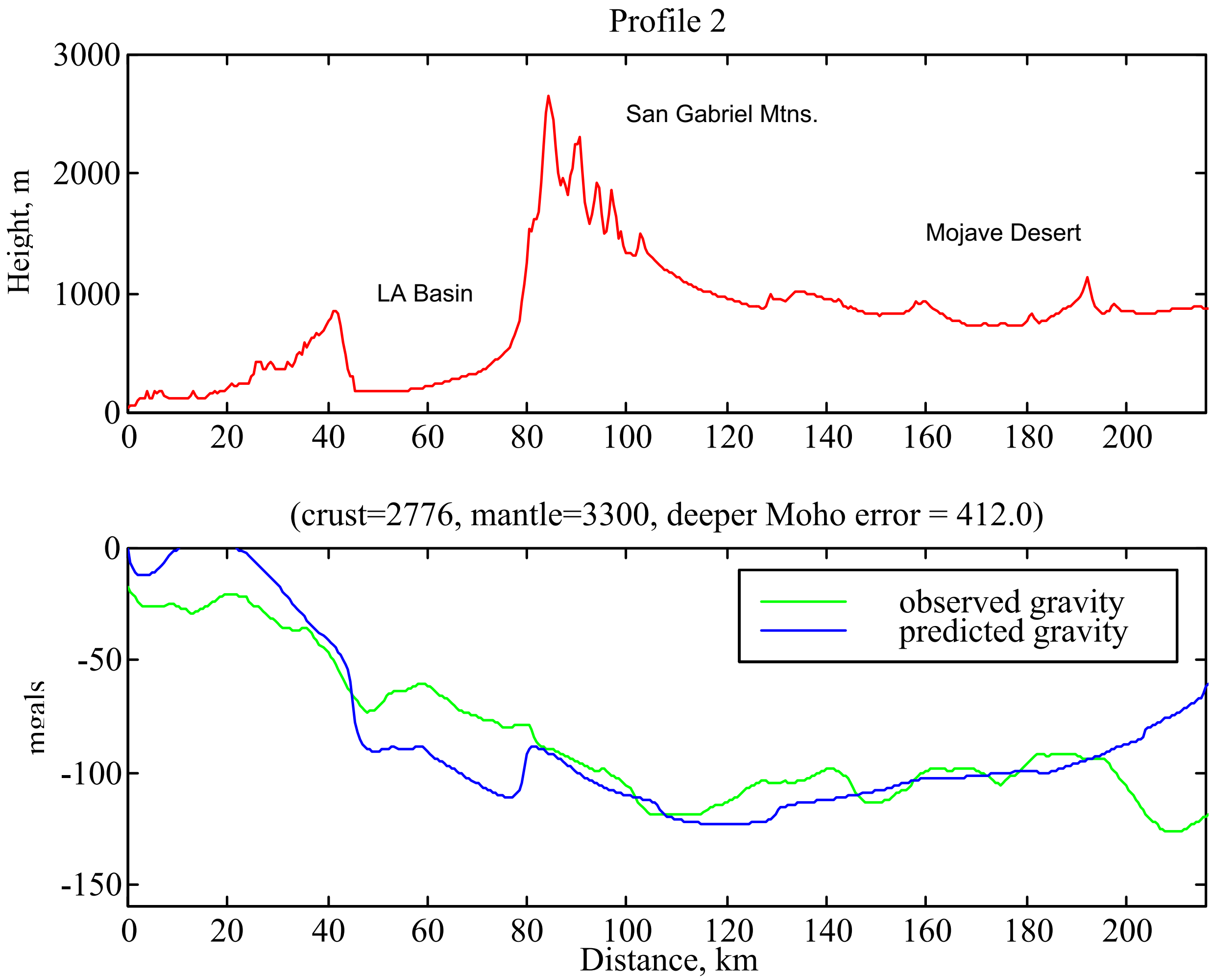

Figure 19 (a). Plot of topography along Profile 2 in Figure 1. (b) Best fit for gravity in the Mojave Desert is obtained with $\rho_{crust} = 2776$ kg/m^3 and $\rho_{mantle} = 3300$ kg/m^3. To improve the fit in the Mojave Desert, we increased the Moho depth in this region.

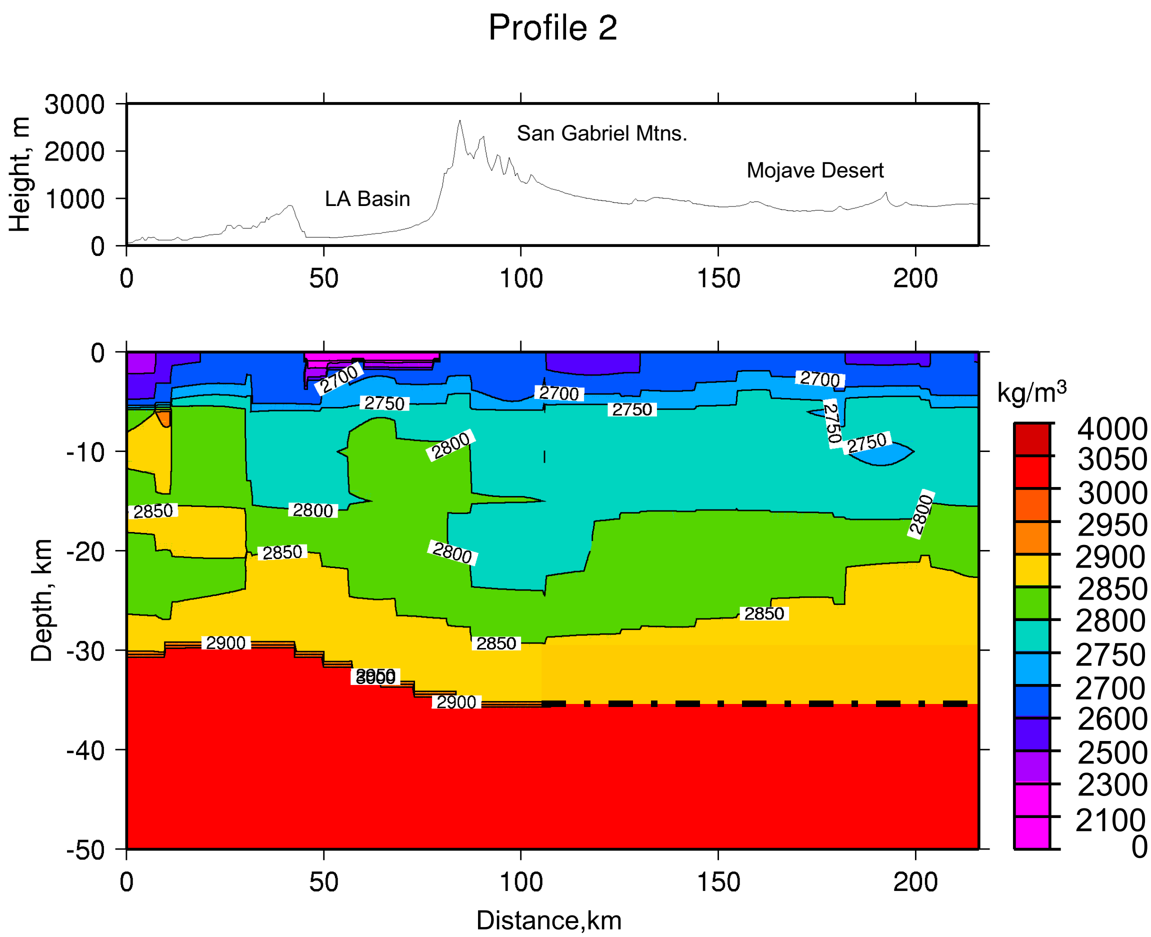

Figure 20 (a). Plot of topography along Profile 2 in Figure 1. (b) The Moho structure that best fits the gravity in the Mojave Desert. Contour plot of densities along Profile 2 inferred from the velocities in Figure 9, but with a deeper Moho depth (2900 kg/m^3 contour above) in the Mojave Desert.

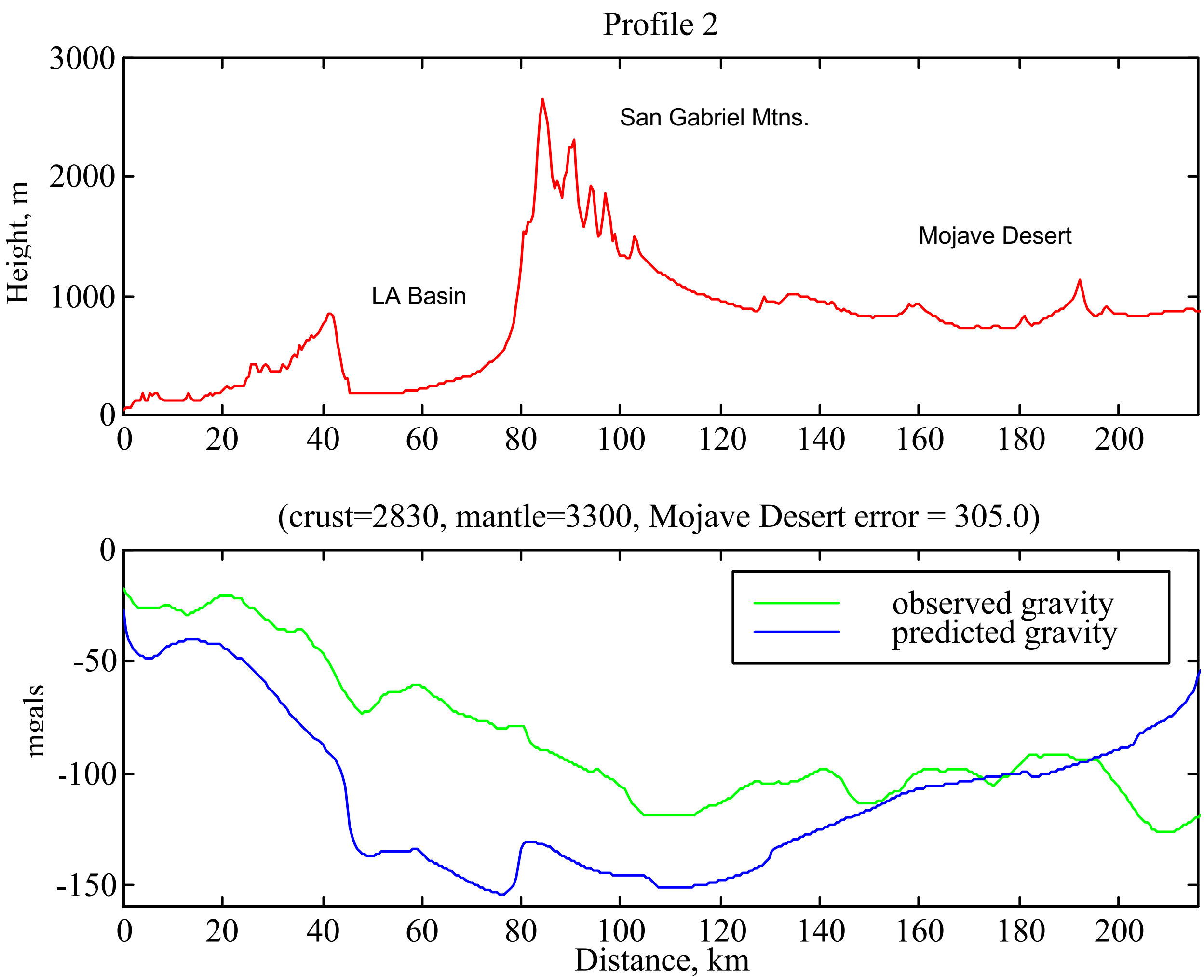

Figure 21 (a). Plot of topography along Profile 2 in Figure 1. (b) Best fit for in the Mojave Desert by increasing the average density of the crust is obtained with $\rho_{crust} = 2830\ kg/m^3$ and $\rho_{mantle} = 3300\ kg/m^3$.

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.

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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
5/00 – 9/00

Southern California Earthquake Center, University of Southern California, Los Angeles, California
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 demagmatometers.

Additional work experience available on request

Conference Presentations

Constraints on the Southern California Earthquake Center (SCEC) 3DVelocity 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