Determination of the Crustal Thicknesses of Parts of South-South, Nigeria, Using Bouguer Gravity Data

Thomas Bolou and Udensi, E. Emmanuel
Department of Physics, Niger Delta University, Bayelsa State, Nigeria
boloucroft@gmail.com
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Abstract

This study presents two-dimensional (2D) gravity modeling of the South-South Nigeria crust to investigate its subsurface structure and tectonic stability. The study area, bounded by Latitude 6.00°E–7.00°E and Longitude 4.00°N–5.00°N, was analyzed using Bouguer gravity data to construct detailed 2D models. These models delineate the sedimentary layers, basement, and mantle boundaries, providing insights into the region's crustal structures. The 2D models reveal sedimentary thicknesses ranging from 5.20 km to 12.00 km and crustal thickness varying between 29.00 km and 40.00 km. Density contrasts between the layers were determined, with average densities of 2.54 g/cm³ for sediments, 2.66 g/cm³ for the basement, and 2.62 g/cm³ for the upper mantle. The results indicate that the crustal thickness in South-South Nigeria varies smoothly and is notably thinner compared to Northern Nigeria. The absence of major fault zones or tectonic boundaries suggests that the region is tectonically stable.

Keywords: *2-D modeling techniques, Basement depth, Conrad discontinuity and Moho discontinuity*

1. Introduction

The inner core, outer core, mantle, and crust are the several layers that make up the Earth's structure, which is arranged according to composition and physical properties. The inner core, which has a radius of around 1,220 km and is mostly composed of solid iron and nickel, is located near the centre of the planet (Aubert et al., 2017). Due to extreme pressure and radioactive decay, temperatures in this layer can reach 5,000 to 6,000 degrees Celsius (Hernlund & Lev, 2010). The outer core, which starts around 5,150 kilometres below the Earth's surface, is molten in contrast to the solid inner core (Gubbins & Bloxham, 2006). Significant temperature and pressure variations characterise the transition between these two layers, aiding in the iron-nickel alloy's solidification (Steinberger et al., 2010).

From the mantle's edge to the inner core, the outer core—which is made up of liquid iron and nickel—stretches for around 2,200 km (Davis & Gubbins, 2013). The geodynamo mechanism, which creates Earth's magnetic field, depends on the fluid motions in this stratum. According to Tarduno et al. (2010), this magnetic field is essential for protecting the Earth from cosmic radiation and the solar wind.

The Earth's deepest layer, the mantle, is located 2,900 kilometres below the outer core. It has sluggish, convective motions across geological timeframes and is made up of silicate minerals that are high in iron and magnesium (McDonough & Sun, 1995). Plate tectonics, which shapes the Earth's surface through processes including mountain creation, earthquakes, and volcanic eruptions, is driven by these motions.

Together with the upper mantle, the crust—Earth's topmost layer—is classified as either continental or oceanic (Rudnick & Fountain, 1995). This lithosphere's tectonic plates move on top of the semi-fluid asthenosphere, causing geological processes including seafloor spreading and mountain formation (Müller et al., 2008). knowledge Earth's geological processes and development requires a knowledge of these strata and how they interact.

Where tectonic plates separate, magma can rise from the mantle and solidify at mid-ocean ridges to generate new crust. This process is known as divergent boundary. The Earth's surface is actively reshaped by this seafloor spreading process, which is linked to earthquakes and volcanic activity (Kearey, Brooks, & Hill, 2009). Magma can rise as a result of reduced mantle pressure caused by plate tectonics, forming new oceanic crust. These processes take place on mid-ocean ridges, which are vast underwater mountain ranges created by the constant formation of crust (Turcotte & Schubert, 2014; Macdonald, 2001).

Additionally, mid-ocean ridges support distinct ecosystems surrounding hydrothermal vents, where life flourishes in mineral-rich waters via chemosynthesis rather than photosynthesis (Van Dover, 2000). Divergent boundaries—like the East African Rift—appear as rift zones on land, demonstrating how these processes can result in significant geological changes, including the possible formation of new ocean basins (Ebinger, 2005).

Tectonic plate collisions create convergent borders, which frequently cause one plate to be thrust beneath the other in a process known as subduction. Mountain ranges, volcanic arcs, and deep ocean trenches are all products of subduction (Grotzinger et al., 2014). The denser oceanic plate subducts beneath the continental plate along oceanic-continental convergent boundaries, forming volcanic arcs along the Pacific Ring of Fire and the Andes Mountains (Harrison et al., 2017; Smithsonian Institution, 2020). Deep trenches and volcanic island arcs, like the Mariana Trench and the Japanese islands, are created by oceanic-oceanic convergent boundaries (Schmidt et al., 2015).

Frequent earthquakes and strike-slip faults, such as the San Andreas Fault, define transform borders, where tectonic plates slide past one another (Riley et al., 2019). Ocean basins, mountain ranges, and volcanic arcs are examples of the structures that are created by interactions at divergent, convergent, and transform borders. Geological and biological systems are also greatly impacted by these processes. Assessing geological risks, investigating natural resources, and learning more about the processes that continuously sculpt our world all depend on an understanding of tectonic limits.

2. Geology of the Area

The South-South region of Nigeria, where the study area is situated, is renowned for its complex geological past. Located in the southern portion of the country, bordering the Gulf of Guinea, this area has a tropical environment with year-round high temperatures and humidity. Rivers and Bayelsa were the two states that were the subject of the study.

Latitudes 6°00'E to 7°00'E and longitudes 4°00'N to 5°00'N define the research region geographically. Its 16-page format guarantees full and in-depth content for in-depth study and research. This division makes it possible for researchers to focus on particular facets of the field, which promotes a methodical approach to the investigation.

All things considered, the research area's location and size offer an intriguing backdrop for investigation, providing insightful information on the ecosystem and features of the area.

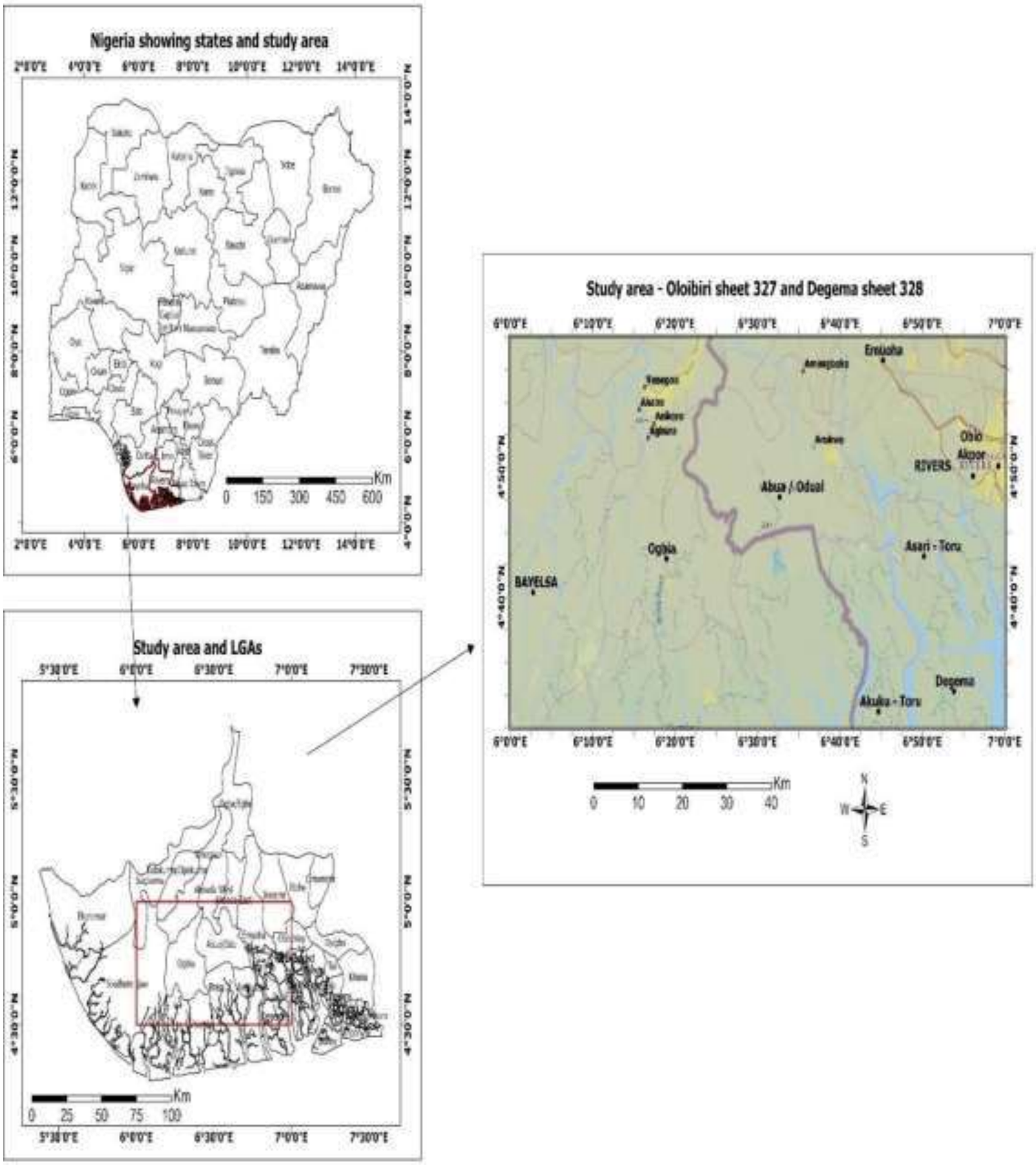


Figure 1: Geological Map of Nigeria showing location of the study area

3. Materials and Methods

Materials

This study investigated the geology of Nigeria's south-south region using Bouguer anomaly maps acquired from the Nigeria Geological Survey Agency (NGSA). The half-degree sheet maps were analyzed with specialized software, facilitating comprehensive data processing and interpretation. This analysis produced detailed maps and profiles, providing valuable insights into the region's geological structure.

Equipment

The materials used for this study include the following:

- Gravity data of the study area
- HP Dual core 15-inch Laptop (3G RAM, 64 bits, 1.67 GHz)
- Computer Softwares
  - Oasis Montaj Version 6.4.2
  - Microsoft Excel software

Methods

The study basically integrated 2D techniques:

- 2D Modelling

4. 2-D Modelling

2-D modeling in geophysics serves both as a data analysis tool and an educational resource, typically marking the final stage of interpretation. It allows for comparisons between finite element calculations and analytical solutions, producing reliable estimates of subsurface structures, particularly the Moho depth. Geosoft's GM-SYS software is commonly used for this purpose, enabling researchers to digitize profiles and adjust model parameters interactively to enhance the match between observed and calculated Moho depths.

In 2-D modeling, profiles are drawn across relatively undisturbed areas, perpendicular to Bouguer gravity anomaly maps, focusing on lithological effects rather than topography. This approach helps in estimating the Moho depth and analyzing the subsurface structure. The software creates a comprehensive model that includes the Moho depth, basement surface, and any intrusions, providing insights into the subsurface.

The iterative process of adjusting model parameters ensures that the final model accurately reflects the subsurface structure. This method also helps identify regions with significant density variations or structural anomalies, which may warrant further study. By analyzing gravity anomaly data, researchers can gain a better understanding of the Earth's crust and underlying geological processes.

In this study, 2-D modeling was used to estimate Moho depth and validate results against existing data and literature. Its effectiveness lies in its ability to refine models and produce reliable subsurface interpretations. Combined with other geophysical methods, 2-D modeling offers a comprehensive understanding of the Earth's subsurface, advancing geological knowledge.

5. RESULTS AND DISCUSSION

2-D modeling

2-D gravity modeling investigates crustal structures by analyzing Bouguer anomalies, revealing mass distribution and isostatic balance. This research uses two profiles, LINE1 and LINE2, for 2-D modeling with GM-Sys software. Empirical relations' and spectral analysis results were used as a precursor to create the two- dimensional (2D) gravity models of the study area.

Modelling along Profile LINE 1

Profile LINE1 extends northwest-southeast across the study area, intersecting a major anomaly near Yenagoa, Ogbia, Southern Ijaw, Abua/Odual and Arukwo. It captures both positive and negative Bouguer anomalies, ranging from -20 mGal to 9.3 mGal. Modeling results show sedimentary thickness between 5.20 km and 9.80 km, with crustal thickness ranging from 29.00 km to 37.10 km. Apparent densities are 2.52 g/cm³ for sediments, 2.73 g/cm³ for the basement, and 2.67 g/cm³ for the upper mantle.

Modelling along Profile LINE 2

LINE2 runs northeast-southwest across the study area, passing through Akaba, Azikoro, and Degema. It captures positive anomaly values around 9.3 mGal and a minimum of -20 mGal, with missing data due to a river. Sedimentary thickness ranges from 6.80 km to 12.00 km, and crustal thickness from 36.00 km to 40.00 km. Apparent densities are 2.56 g/cm³ for sediments, 2.60 g/cm³ for the basement, and 2.58 g/cm³ for the upper mantle.

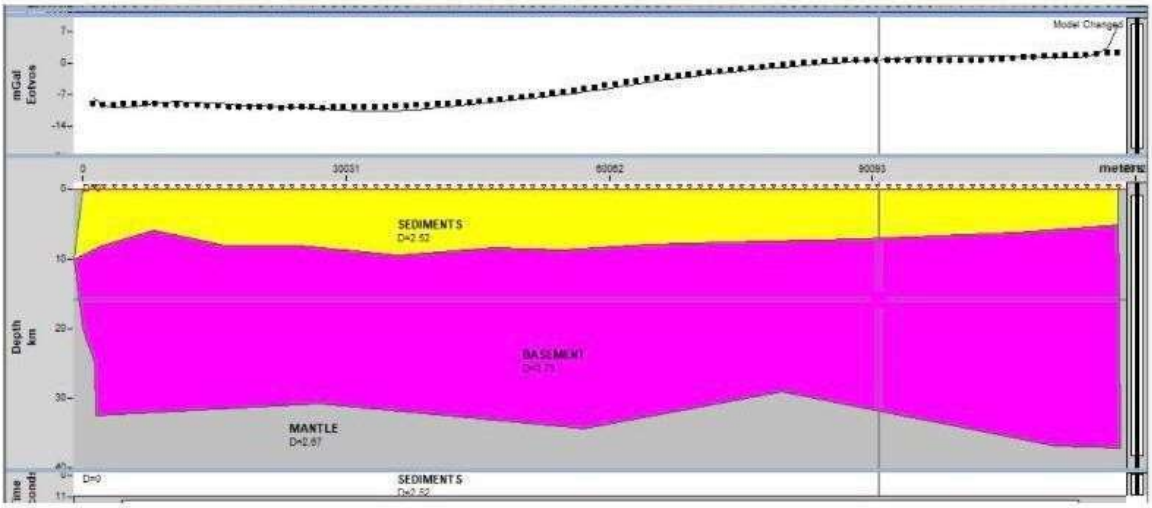


Figure 6: Crustal Modelling along profile line-1

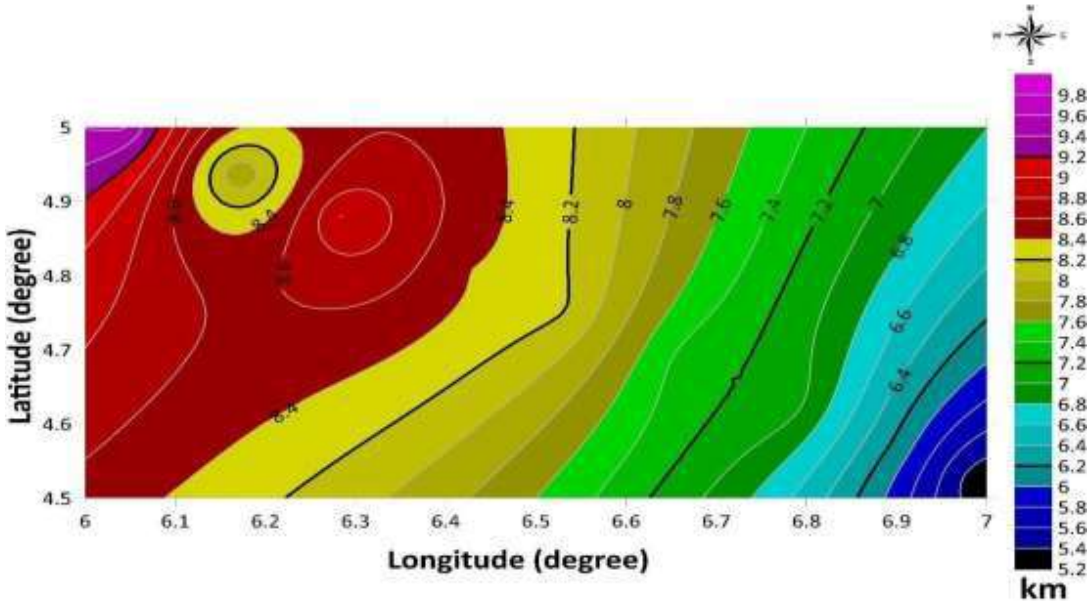


Figure 7: Sedimentary thickness along profile line-1

Figure 8: Crustal thickness along profile line-1

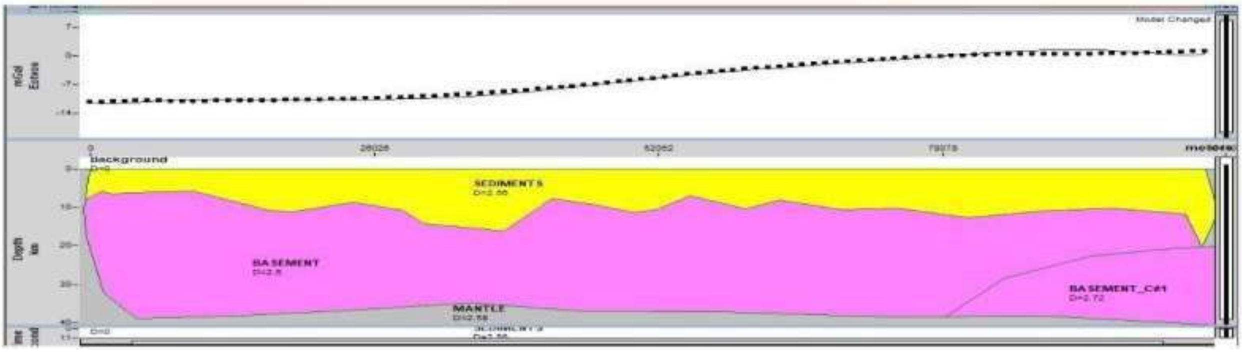


Figure 9: Crustal Modelling along profile line-2

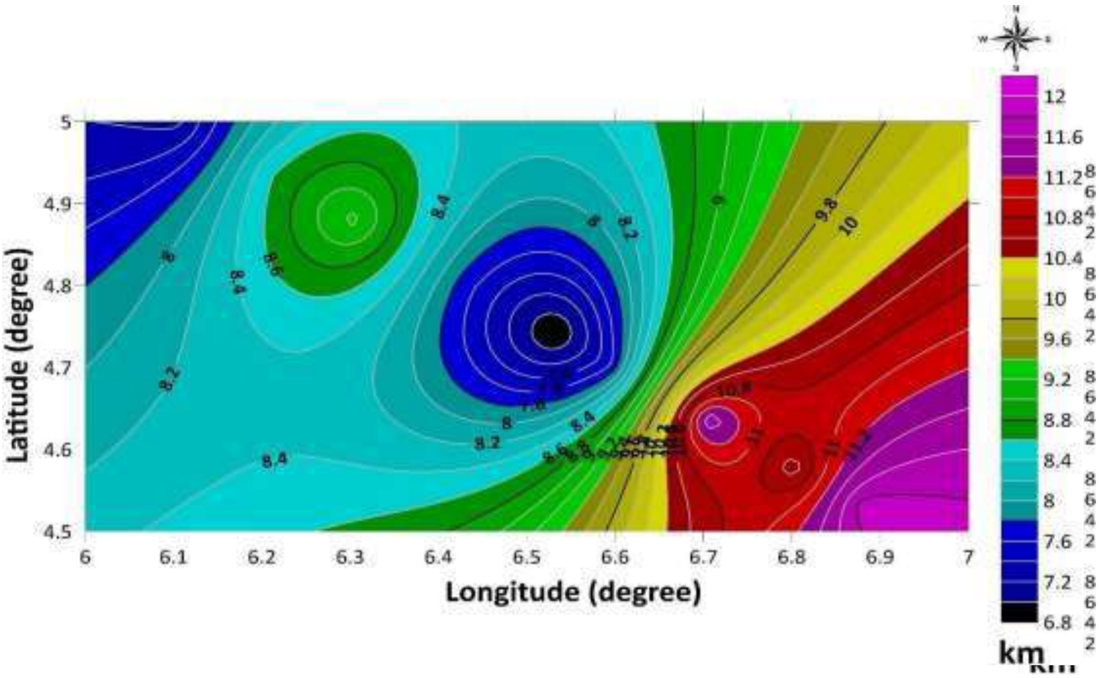


Figure 10: Sedimentary thickness along profile line-2

Figure 11: Crustal thickness along profile line-2

Tectonic Evaluation of the Study Area

In the study area, the crustal thickness ranges from 29.00 km to 40.00 km. However, similar thicknesses are found in earthquake-prone countries like India and Japan. This suggests that tectonic stability cannot be determined by crustal thickness alone. Factors like tectonic setting, fault activity, and stress regime are also crucial. Nigeria, located far from plate boundaries, is considered to be tectonically stable.

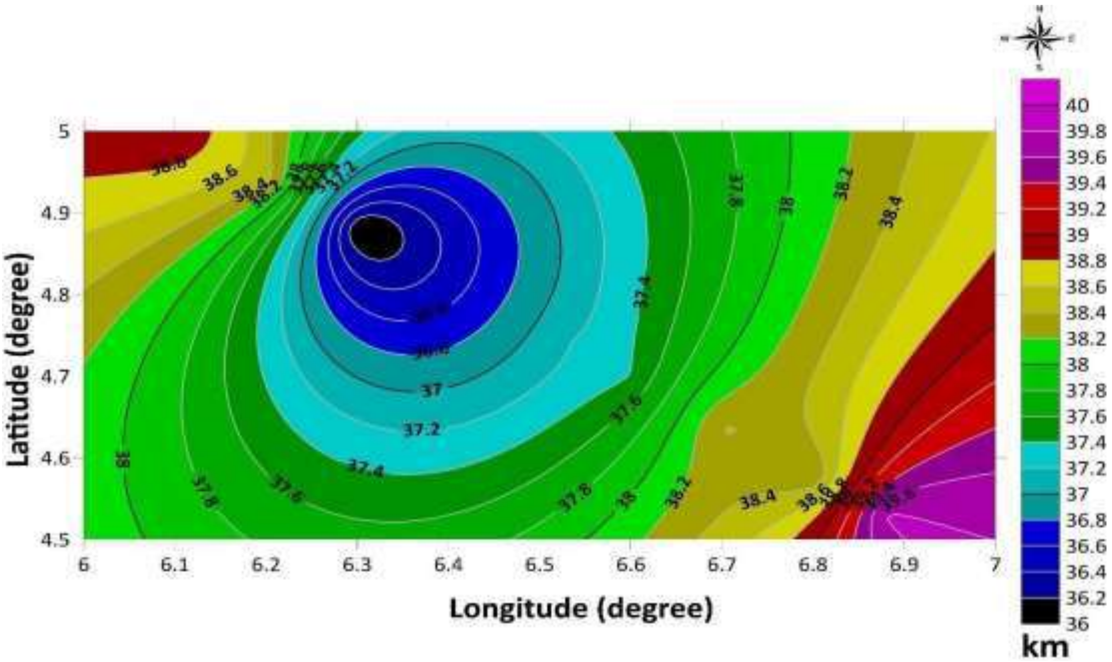
6. Summary and Conclusion

The study applied three methods—empirical relations, spectral analysis, and 2D gravity modeling—to investigate crustal structures in the study area:

2D Modeling

▪ **Sedimentary thickness:** 5.20 km to 12.00 km.

▪ **Crustal depth:** 29.00 km to 40.00 km.



▪ **Average densities:** 2.545 g/cm³ (sediments), 2.665 g/cm³ (crust), and 2.625 g/cm³ (upper mantle).

The results indicate the area is suitable for oil exploration and can inform future geological models and drilling strategies.

References

Aubert, J., Tarduno, J. A., & Johnson, C. L. (2017). The role of the Earth's inner core in generating its magnetic field. *Nature, 542(7640),* 386-389.

Davis, A. L., & Gubbins, D. (2013). The geodynamo: Magnetic field generation in the Earth's core. *Nature Geoscience, 6(10),* 862-865.

Ebinger, C. J. (2005). Continental breakup: The East African perspective. *Geological Society of America Bulletin, 117(7-8),* 1009-1022.

Grotzinger, J., Jordan, T. H., Press, F., & Siever, R. (2014). *Understanding Earth*. W.H. Freeman and Company.

Gubbins, D., & Bloxham, J. (2006). Geodynamo modeling and the role of Earth's inner core. *Physics of the Earth and Planetary Interiors, 155(3-4),* 249-260.

Harrison, T. M., Celerier, J., Aikman, A. B., et al. (2017). Mountains, climate, and erosion. *Annual Review of Earth and Planetary Sciences*, 36, 289-309.

Hernlund, J. W., & Lev, E. (2010). Radioactive decay and the temperature of Earth's core. *Geophysical Research Letters, 37(9),* L09309.

Kearey, P., Brooks, M., & Hill, I. (2009). *An Introduction to Geophysical Exploration*. Wiley-Blackwell.

Macdonald, K. C. (2001). Mid-ocean ridges: Fine-scale tectonic, volcanic, and hydrothermal processes within the plate boundary zone. *Annual Review of Earth and Planetary Sciences*, 19, 263-286.

McDonough, W. F., & Sun, S.-S. (1995). The composition of the Earth. *Chemical Geology, 120(3-4),* 223-253.

Müller, R. D., Roest, W. R., Royer, J.-Y., et al. (2008). Age, spreading rates, and spreading asymmetry of the world's ocean crust. *Geochemistry, Geophysics, Geosystems, 9(4),* Q04006.

Riley, P., Lockwood, M., Owens, M. J., et al. (2019). Predicting the occurrence and magnitude of extreme space weather events. *Nature Communications, 10(1),*4837.

Rudnick, R. L., & Fountain, D. M. (1995). Nature and composition of the continental crust: A lower crustal perspective. *Reviews of Geophysics, 33(3),* 267-309.

Schmidt, M. W., Connolly, J. A. D., & Wenz, M. (2015). Subduction zone melting and the formation of Earth's continental crust. *Nature, 482(7384),* 84-87.

Smithsonian Institution. (2020). The Pacific Ring of Fire: Seismic and volcanic activity around the Pacific. *Global Volcanism Program*.

Steinberger, B., Torsvik, T. H., & Tackley, P. J. (2010). How supercontinents and superplumes affect the core–mantle boundary region. *Science, 328(5974),* 254-257.

Tarduno, J. A., Cottrell, R. D., Smirnov, A. V., et al. (2010). A record of the intensity of Earth's magnetic field during the last 160 million years. *Science, 327(5973),* 1238-1240.

Turcotte, D. L., & Schubert, G. (2014). *Geodynamics.*Cambridge University Press.

Van Dover, C. L. (2000). The ecology of deep-sea hydrothermal vents. *Princeton University Press.*