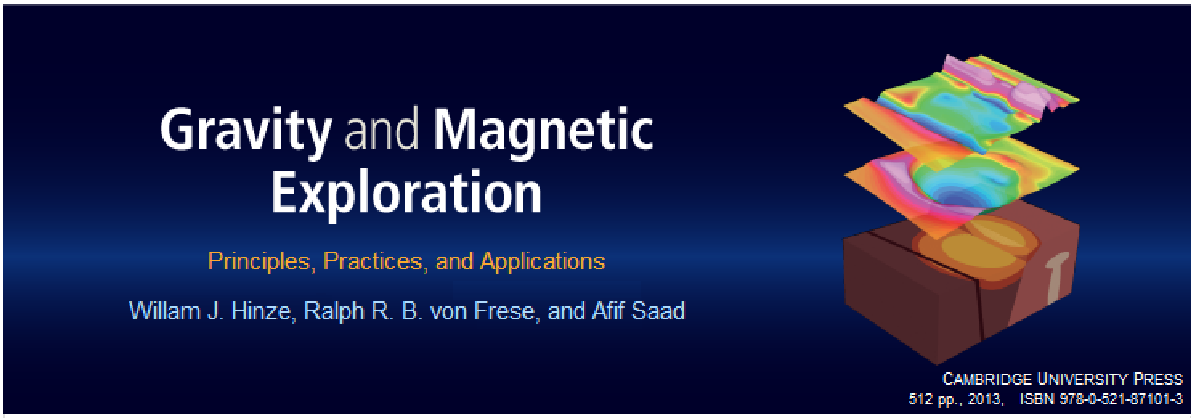

Minnesota Gravity and Magnetic Anomalies

for

Gravity and Magnetic Exploration: Principles, Practices, and Applications

(W.J. Hinze, R.R.B. von Frese, and A.H. Saad, 2013, Cambridge University Press, ISBN: 978-0-521-87101-3)

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1. Minnesota Gravity & Magnetic Anomalies

Introduction

This exercise involves processing and interpretation of selected magnetic and gravity anomaly data from four study areas in the State of Minnesota. The data analysis and graphics procedures outlined in the accompanying Oasis montaj tutorial are applicable to this exercise as well as other Geosoft-based exercises involving gravity and magnetic datasets.

The study areas are delimited to illustrate a range of magnetic and gravity anomalies and to minimize the size of the anomaly grids so as to expedite their processing. They are located within the region bounded by 91° 30′ − 94°W longitude and 46° − 47°30′ N latitude that includes Minnesota and adjacent regions. The total magnetic intensity and Bouguer gravity anomalies of this region are shown in Figures 1.1 and 1.2, respectively. The comparison of the two anomaly maps of Minnesota in Figure 1.3 suggests numerous spatial anomaly correlations that may help reveal or constrain further insights on the underlying geology in Figure 1.4.

The Minnesota area involves complex Precambrian geology [Chandler et al., 2007] ranging in age from roughly 3.5 to 1.1 Ga including terranes with a wide variety of structures and lithologies derived from several tectonic episodes [Figure 1.4]. The eastern portion of the area is underlain by igneous and sedimentary rocks of the 1.1 Ga Midcontinent Rift System [Hinze et al., 1997]. Components of this Keweenawan rift system in the study area include the basalt volcanic rocks of the St. Croix Horst, the Bayfield Basin to the west of the horst composed largely of detrital sedimentary rocks, and the layered gabbro intrusive, the Duluth Complex, which intruded volcanic rocks of the rift along the northwest shore of Lake Superior. The central St. Croix horst is bounded by major thrust faults that bring volcanic rocks into juxtaposition with the sedimentary rocks of the adjacent basin. West of the rift system the bedrock that is overlain by generally thin [< 110 m] Pleistocene glacial till consists of a complex of Archean rocks of the Superior province.

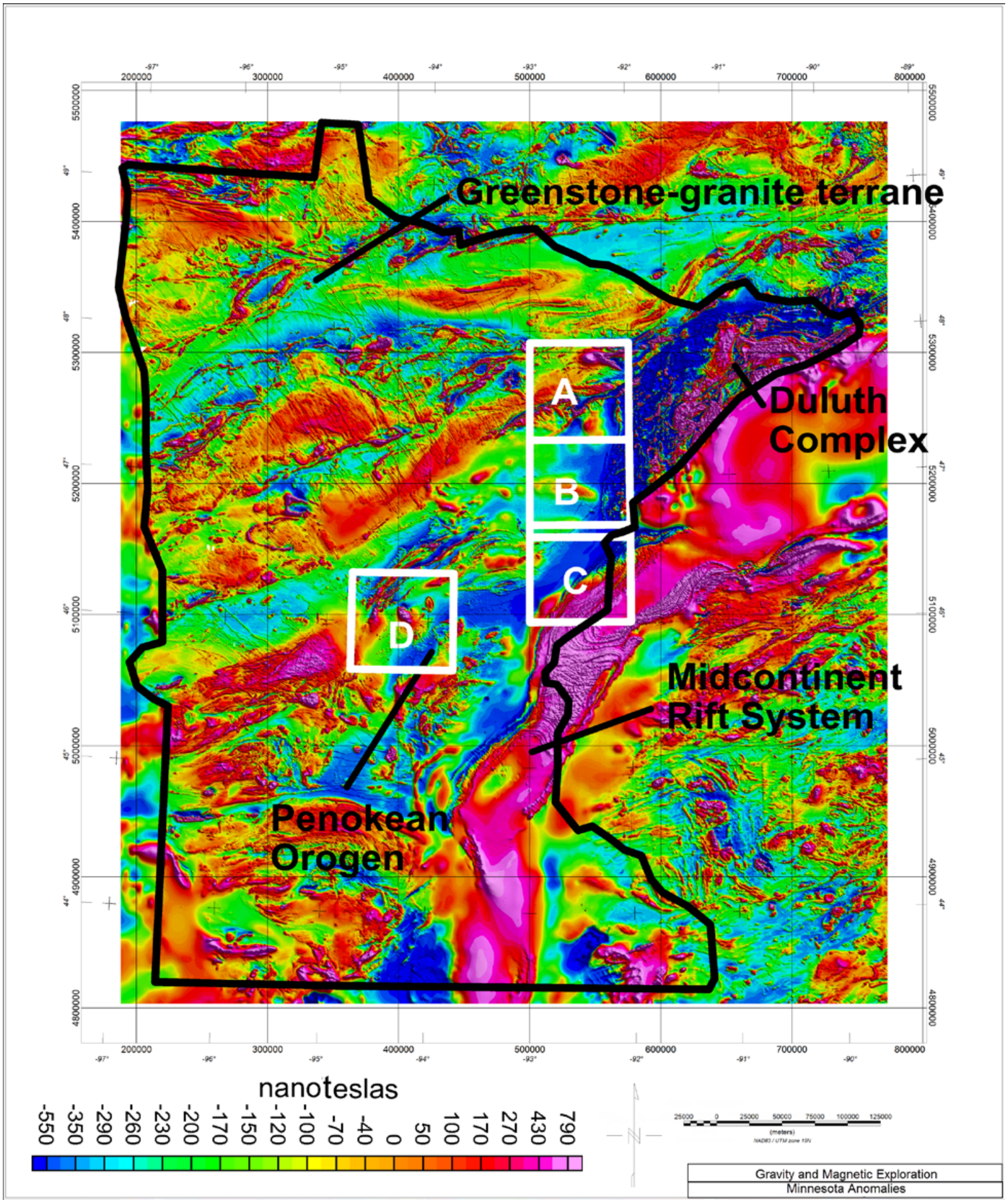


Figure 1.1: Microleveled total field aeromagnetic survey anomalies of Minnesota and adjacent regions with the study areas outlined that are considered in the Geosoft-based exercises. Geomagnetic north is to the top of the map. Adapted from Chandler [1991].

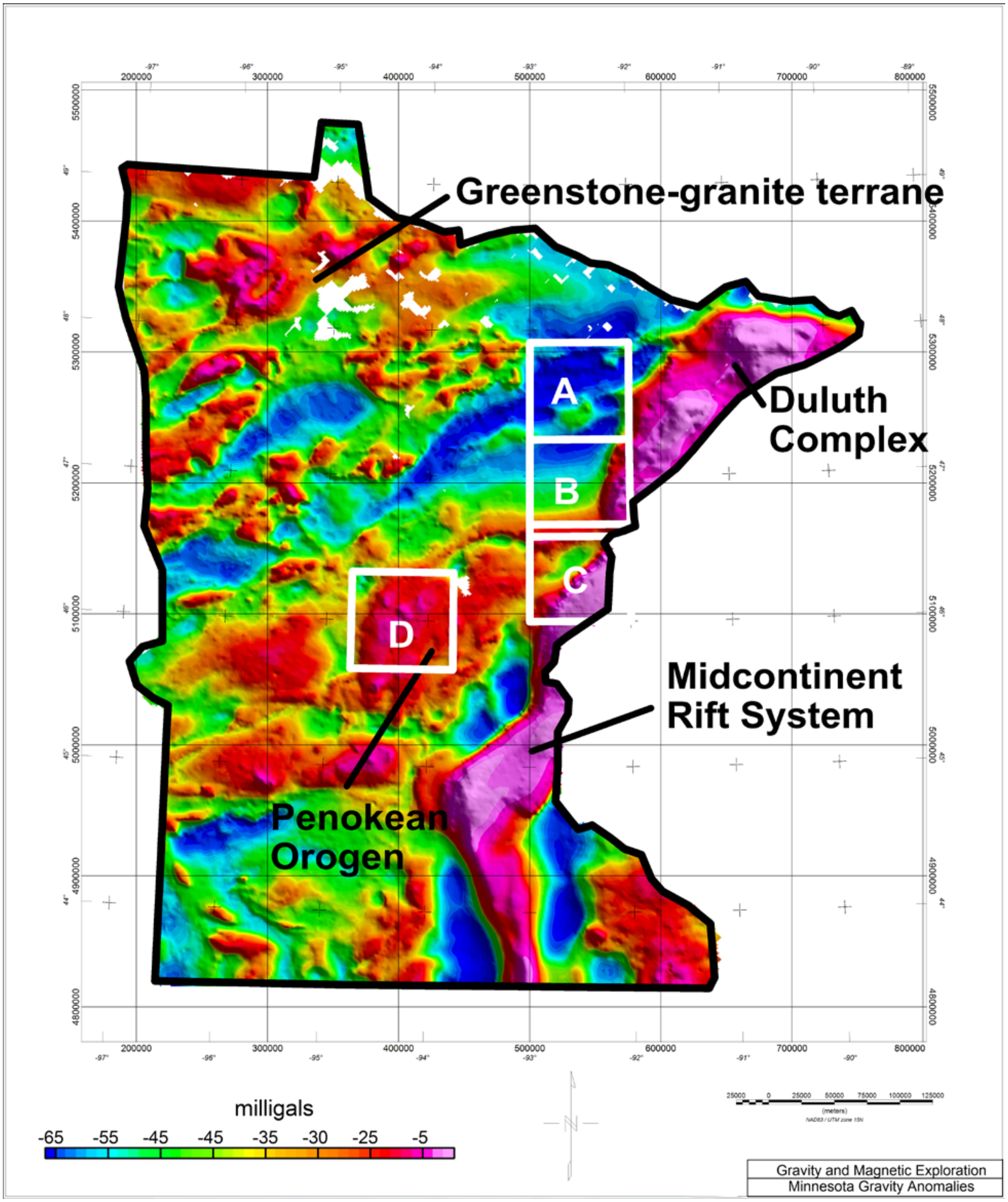


Figure 1.2: Bouguer gravity anomalies of Minnesota with the study areas outlined which are considered in the Geosoft-based exercises. Adapted from Chandler and Schaap [1991].

Within the study area these rocks consist primarily of a greenstone-granite complex dated at roughly 2.7 Ga which is manifested as a series of steeply dipping belts of metavolcanic and metasedimentary rocks separated by elongated granite batholiths.

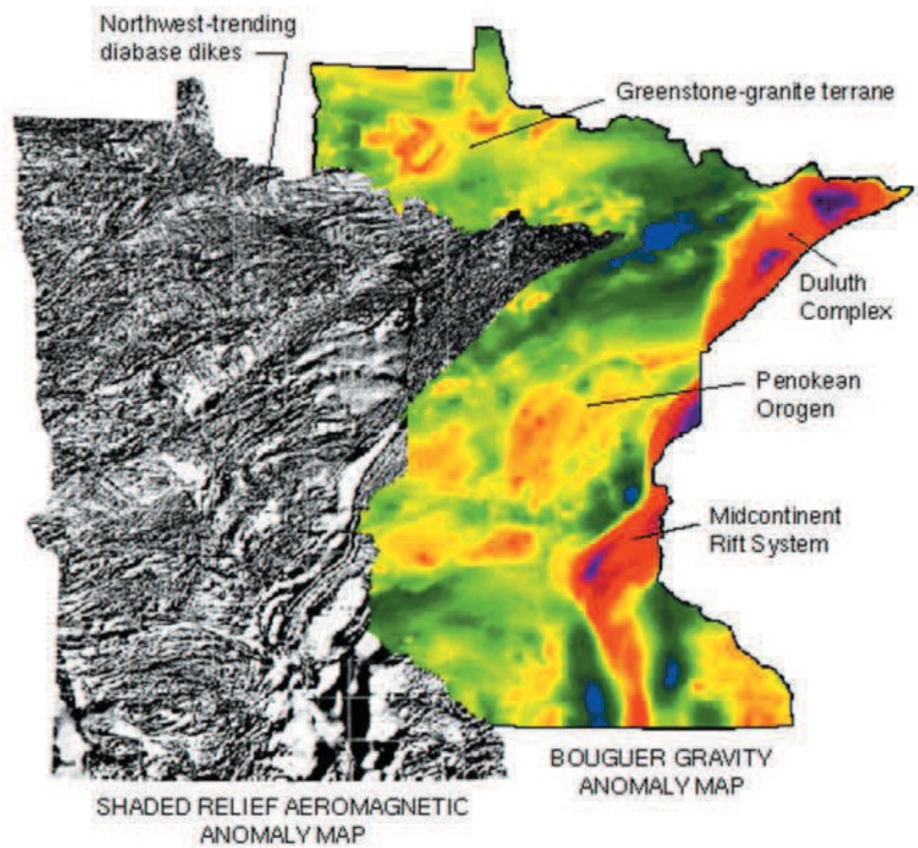


Figure 1.3: Bouguer gravity anomalies [colored] and shaded relief aeromagnetic anomalies of Minnesota. Adapted from Chandler and Schaap [1991].

Paleoproterozoic rifting [≈ 2.1 Ga] is noted by the north-northwest striking diabase dikes that cut the older Archean rocks. Archean gneiss domes of Paleoproterozoic age also occur along the southern margin of the region. Foreland fold and thrust sedimentary basins of the ~1.85 Ga Penokean orogeny [Schulz and Cannon, 2007] locally overlie the Archean rocks. The rocks of these basins consist of a basal quartzite overlain by iron formation and a thick sequence of greywacke and shale sedimentary rocks.

The complex structure of the Precambrian rocks which are commonly associated with near vertical boundaries and the wide variety of igneous, metamorphic, and sedimentary rocks of the region are reflected in a host of intense gravity and magnetic signatures. These signatures and their geologic significance is the subject of this exercise. Oasis montaj will be used to process aeromagnetic flight line and gravity point station observations to obtain the magnetic and gravity anomalies for the study areas shown in Figures 1.5 and 1.6, respectively.

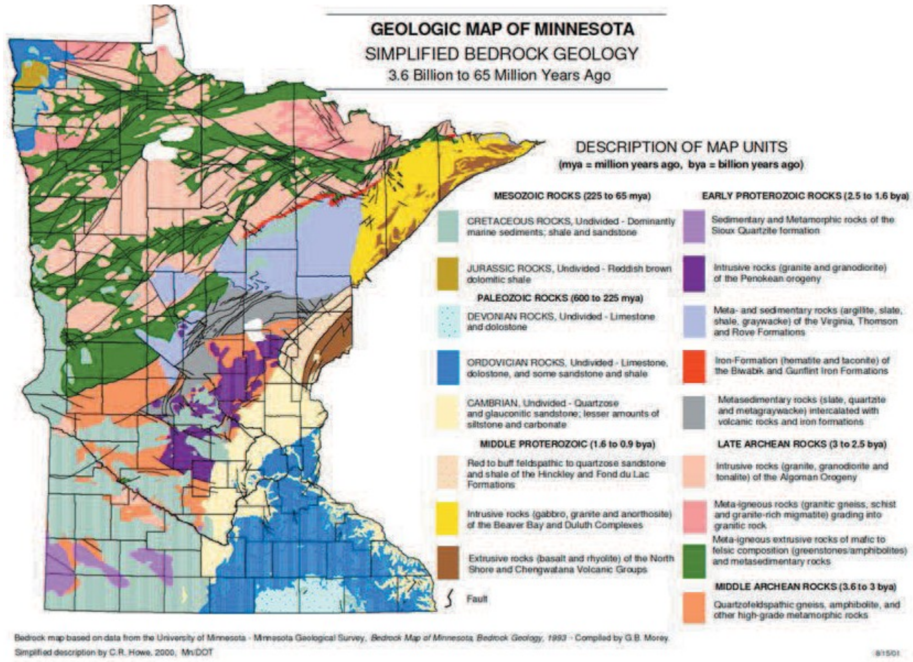


Figure 1.4: Geological map of Minnesota adapted from the Minnesota Geological Survey.

Exercise Objectives

The overall objectives of this exercise include developing experience with Oasis montaj software for mapping, processing, and filtering of gravity and magnetic anomaly data. This involves the import of the datasets into the Oasis montaj software, gridding of the imported data, mapping of the gridded data in various presentation formats, and filtering of the data and presenting the data and processing results in both map and profile formats as appropriate.

In addition, the role of gravity and magnetic anomaly data will be investigated in mapping the geology of a complex Precambrian terrain where the crystalline rocks occur near the surface. The nature of gravity and magnetic anomalies associated with various crystalline rock terrain sources and structures will also be studied.

The exercises in the subsections below emphasize developing experience with anomaly gridding and plotting, processing to enhance specific anomaly characteristics and evaluating the utility of enhancement methods, and correlation analysis in interpretation.

The exercises supplement sections 6.5, 7.2 through 7.4, 12.4, 13.2 through 13.4, A.3, A.5.1, and A.6 of Hinze et al. [2013]. All data plots should include scales, color bars, and other relevant data statistics as described in Appendix A.6.3.

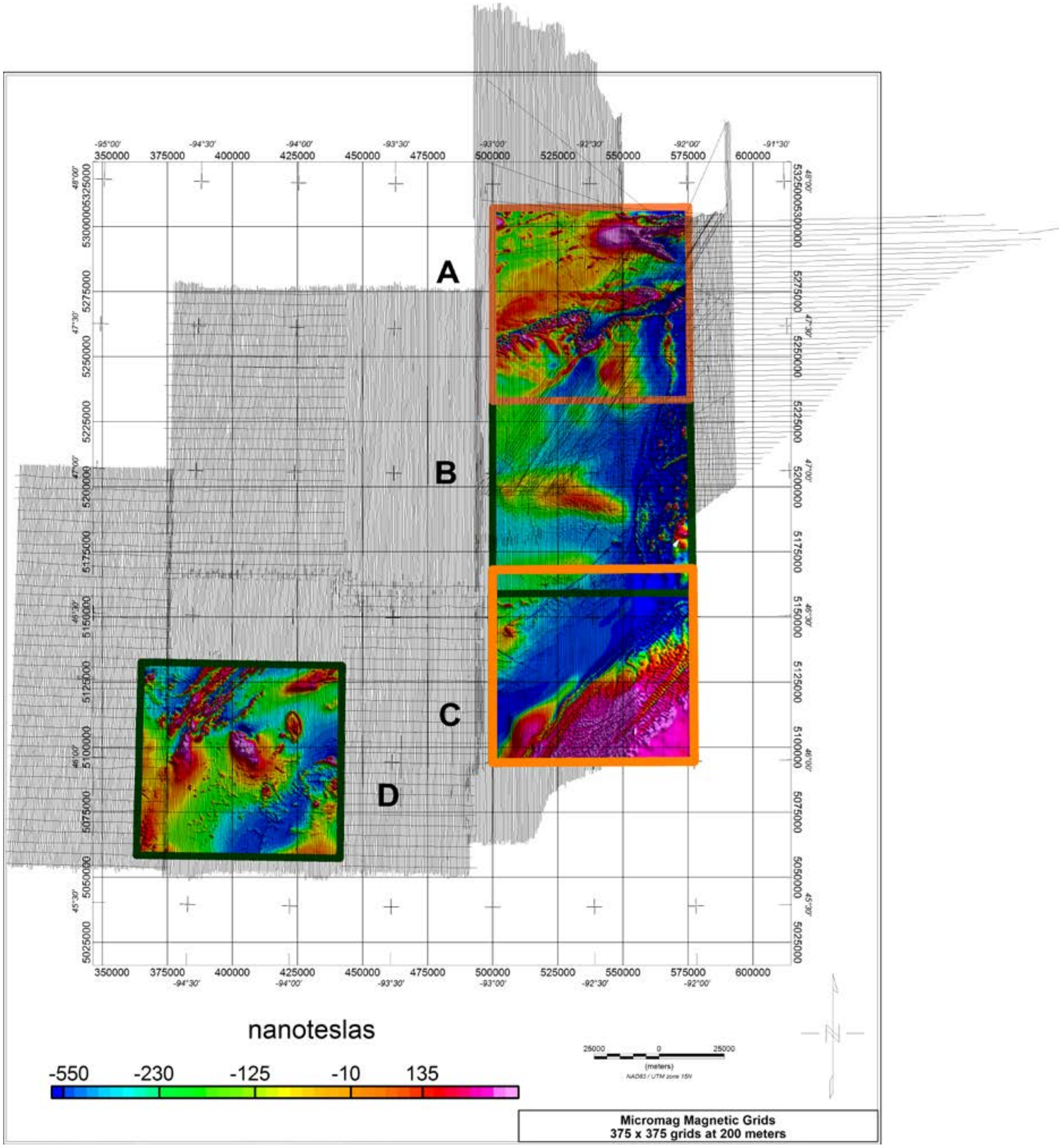


Figure 1.5: Microleveled total field aeromagnetic survey anomalies of the study areas considered in the Geosoft-based exercises. The flight lines are also marked.

Geophysical Datasets

The magnetic anomaly data of the region were primarily observed under the auspices of the Minnesota Geological Survey along north/south flighty paths separated by 400 m at a mean terrain clearance of 150 m [Chandler, 1985, 1991, 1996; Chandler et al., 2007].

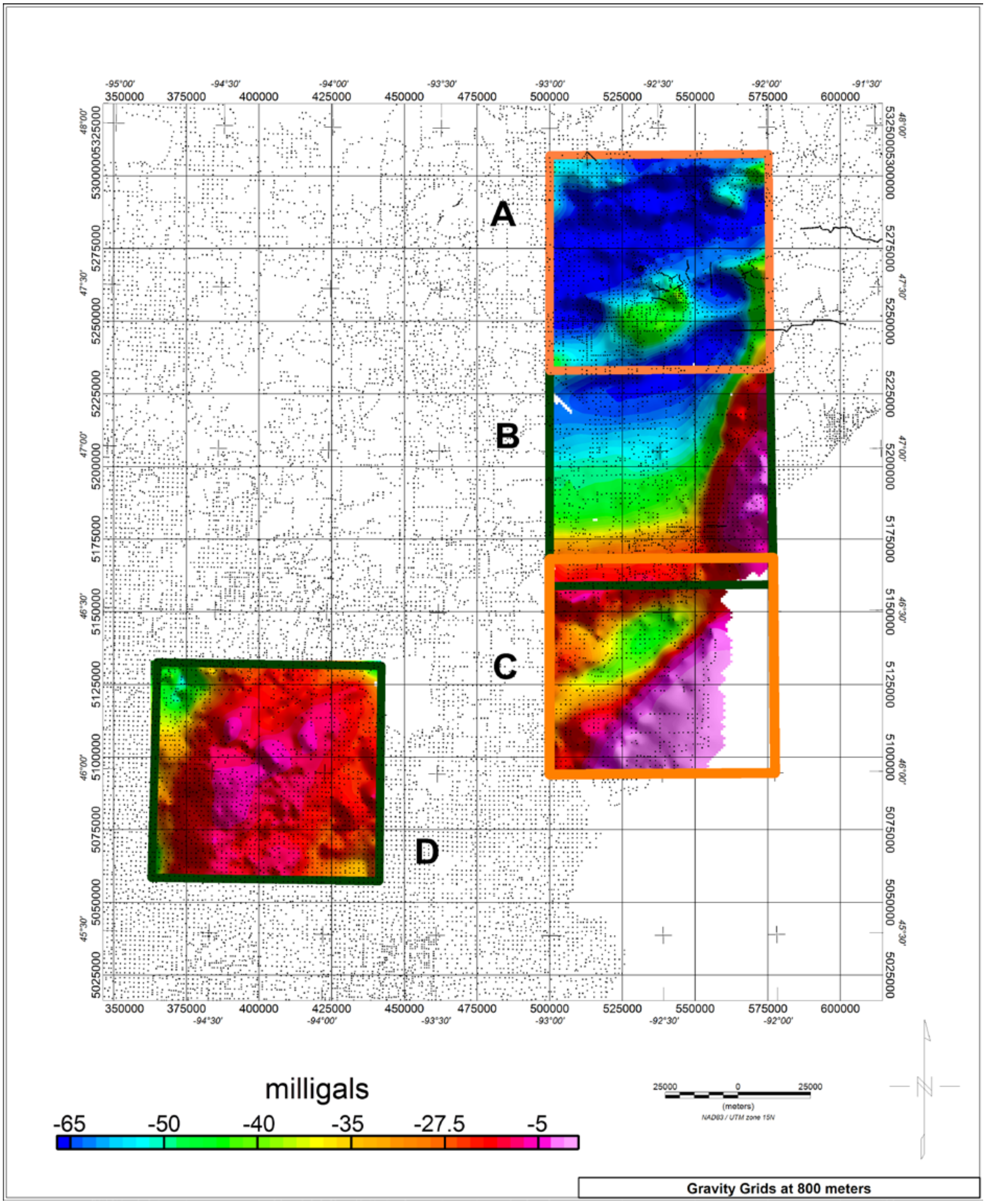


Figure 1.6: Bouguer gravity anomalies of the study areas considered in the Geosoft-based exercises. The station locations of the gravity observations are also shown.

Measurements of the total magnetic intensity were made with a proton-precession magnetometer mounted in a tail stinger at an interval of either 50 or 75 m. The data were leveled with tie-line observations taken at 2- or 4-km intervals and anomaly values were computed using standard methodologies. Subsequently Chandler used the Oasis montaj software to microlevel the aeromagnetic survey data.

Gravity observations were reduced to simple Bouguer gravity anomalies using standard methodologies [Section 6.4 of Hinze et al. (2013)] and a density of 2,670 kg/m^3 for the Earth material from the observation site to the sea level datum [Chandler (1996); Chandler and Schaap (1991)]. Observations were made at intervals generally ranging from 1.6 to 5 km, although the separation may be as large as 10 km where ground access is limited.

Study Area A

Geological Background

Study area A is over the Mesabi Iron Range with boundaries as shown in Figure 1.1. It is located along the boundary of the Paleoproterozoic Animikie Basin on the south and the Archean Superior Province to the north. The largest banded iron formation in the USA, the Biwabik Formation, occurs near the base of the sedimentary rocks of the Basin. This iron formation is the location of the famed Mesabi Iron Range that was originally mined for the non-magnetic hematite ore and more recently for the lower-grade magnetic taconite ores.

The iron formation generally consists of 75% SiO_2 and 25% Fe in silicates, oxides, and carbonates. This formation that strikes west-southwest across the center of the area is marked by an intense magnetic anomaly associated with the magnetite-bearing phases of the formation that is broken by segments related largely to non-magnetic hematite ores.

The Animikie Basin is a foreland basin developed north of the roughly 1.9 Ga Penokean Fold and Thrust Belt immediately south of the Basin. The basal sedimentary formation in the Basin is a quartzite that is overlain by the Biwabik Formation which reaches a thickness of roughly 250 m in the vicinity of the notable fold in the sedimentary rocks, the so-called Virginia Horn, which is located near the center of study area A. In turn the Biwabik Formation is conformably overlain by the Virginia Formation that reaches several kilometers in thickness and consists largely of essentially non-magnetic black shale, greywacke, and ash beds. The general dip of the sedimentary rocks is southeastward at 10° to 20° in this area.

The Basin sedimentary rocks lie unconformably on the 2.7 Ga rocks of the Superior Province that dip under the Basin. Along the margin of the Basin these rocks are primarily intrusive granites, although volcanic sequences occur particularly in the vicinity of the Virginia Horn region.

Magnetic Exercises

1. Grid and plot the aeromagnetic total field anomalies in file MN_Mag_A.XYZ at 200-m intervals by (a) bi-directional [Figure 1.7] and (b) minimum curvature gridding [see examples in the Oasis montaj tutorial]. (c) Compare the two gridded datasets and their statistics emphasizing the relative advantages and limitations of each gridding method for qualitative and quantitative anomaly interpretation.

2. For the bi-directionally gridded aeromagnetic total magnetic field data, describe the (a) anomaly signatures and (b) possible idealized source geometries that may apply in the context of the underlying geology

3. Plot the bi-directionally gridded aeromagnetic total magnetic field anomalies reduced to (a) the pole [RTP], and (b) the equator [RTE]. How do the (c) RTP and (d) RTE anomalies compare with the total field anomalies? (e) Describe the interpretational advantages that the RTP map has over the observed total field and RTE anomaly maps. (f) Justify the assumptions underlying the RTP and RTE anomaly estimates in the context of the available geological constraints on the magnetic anomaly sources

4. Prepare shaded relief maps of the aeromagnetic RTP anomalies sun-lit at inclination 40° from (a) the north, (b) northeast, (c) east, (d) southeast, (e) south, (f) southwest, (g) west, and (h) northwest directions. (i) Discuss the relative advantages and limitations of these shaded relief maps for the geological interpretation of the aeromagnetic total field anomalies. (j) Are any of these maps redundant? (k) How does changing the illumination direction and inclination affect the RTP anomalies?

5. Directionally filter and plot the aeromagnetic RTP anomalies using pass-wedges of 45° centered on (a) the north, (b) northeast, (c) east, (d) southeast, (e) south, (f) southwest, (g) west, and (h) northwest directions. (i) Compare the directionally filtered results with the shaded relief maps in exercise 4-above.

6. Plot the aeromagnetic RTP anomalies continued (a) upward 500 m and (b) 2, 000 m, and (c) downward 120 m. (d) Discuss the relative advantages and limitations of the continuations for the geological interpretation of the magnetic anomalies. Illustrate with examples from the maps.

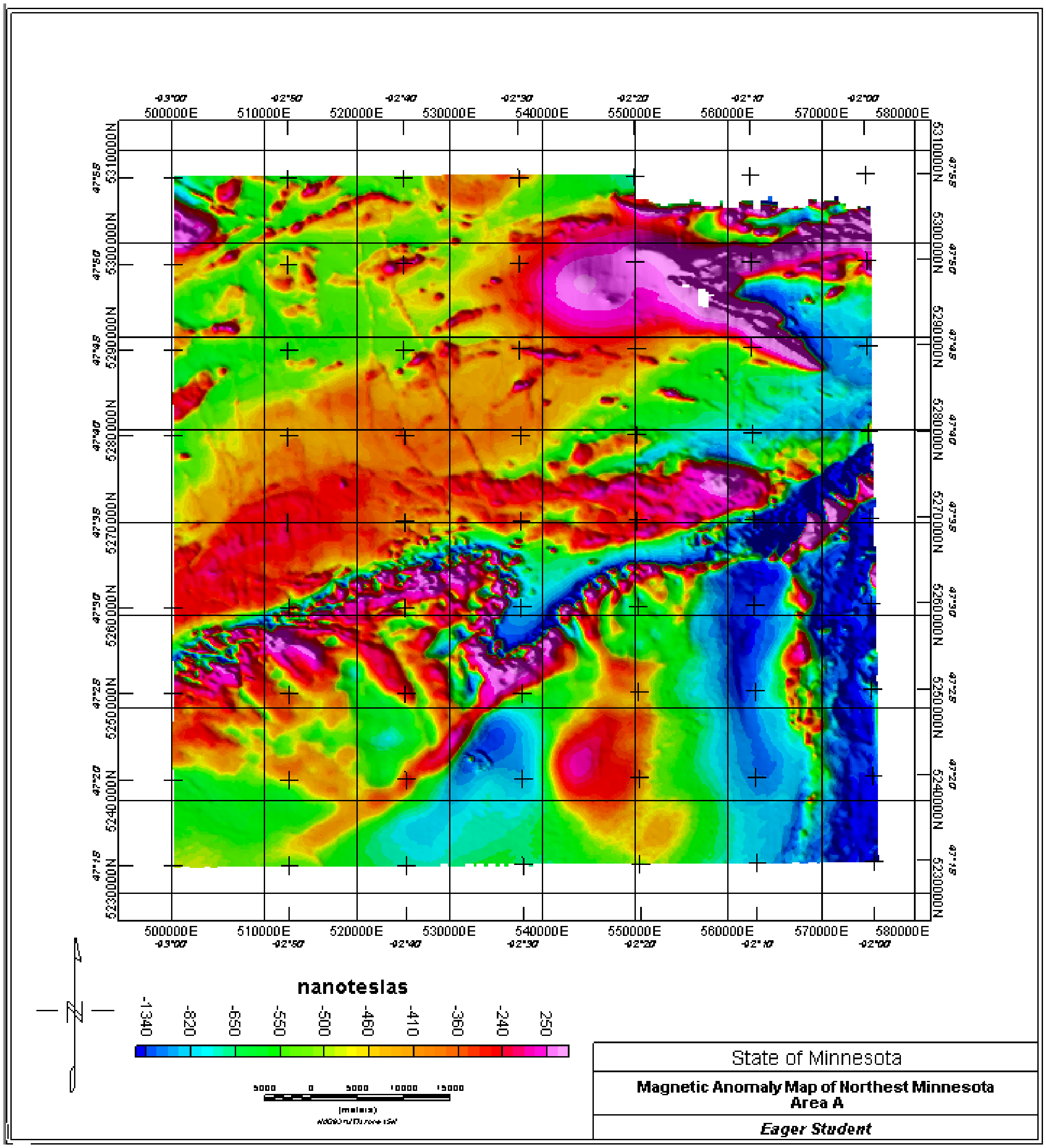


Figure 1.7: Bi-directionally gridded total field aeromagnetic anomalies for study area A with superimposed flight lines. The 400 × 400 anomaly array was evaluated at the altitude of 150 m above the ground surface with a 200-m interval.

7. Plot the aeromagnetic RTP anomalies filtered for wavelengths roughly (a) ≥ 1, 000 m and (b) ≤ 1, 000 m. (c) How do the wavelength filtered results compare with the continuations in exercise 6-above? (d) Discuss the relative advantages and limitations of wavelength filtering as an aid to the geological interpretation of the magnetic anomalies.

8. For the aeromagnetic RTP anomalies, compute and plot (a) the first the horizontal x-, (b) y-, and vertical (c) first and (d) second z-derivative anomalies, as well as the total horizontal (e) first and (f) second derivatives. (g) Discuss the relative advantages and limitations of these derivatives for the geological interpretation of the magnetic anomalies, being specific regarding possible source depths and lateral boundaries for the anomalies of the study area.

9. For the aeromagnetic RTP anomalies, compute and plot (a) an apparent susceptibility map. (b) Compare these results with the derivatives obtained in exercise 8-above. (c) Discuss the relative advantages and limitations of the comparison for geologically interpreting the magnetic anomalies.

10. Prepare a profile of the RTP magnetic anomaly data (a) across the Biwabik Iron Formation west of the Virginia Horn. (b) What characteristics of the anomaly suggest that it has a relatively flat [10° to 20°] dip to the southeast?

11. The long, linear magnetic highs striking nearly north-south across the Superior Province are terminated at the edge of the Animikie Basin. (a) What is the cause of the termination? (b) How could you check this by filtering the magnetic anomaly data?

12. The general negative magnetic anomaly associated with the Animikie Basin is disturbed by numerous positive magnetic anomalies. (a) What is the source of these anomalies, and (b) what is the basis of your conclusion?

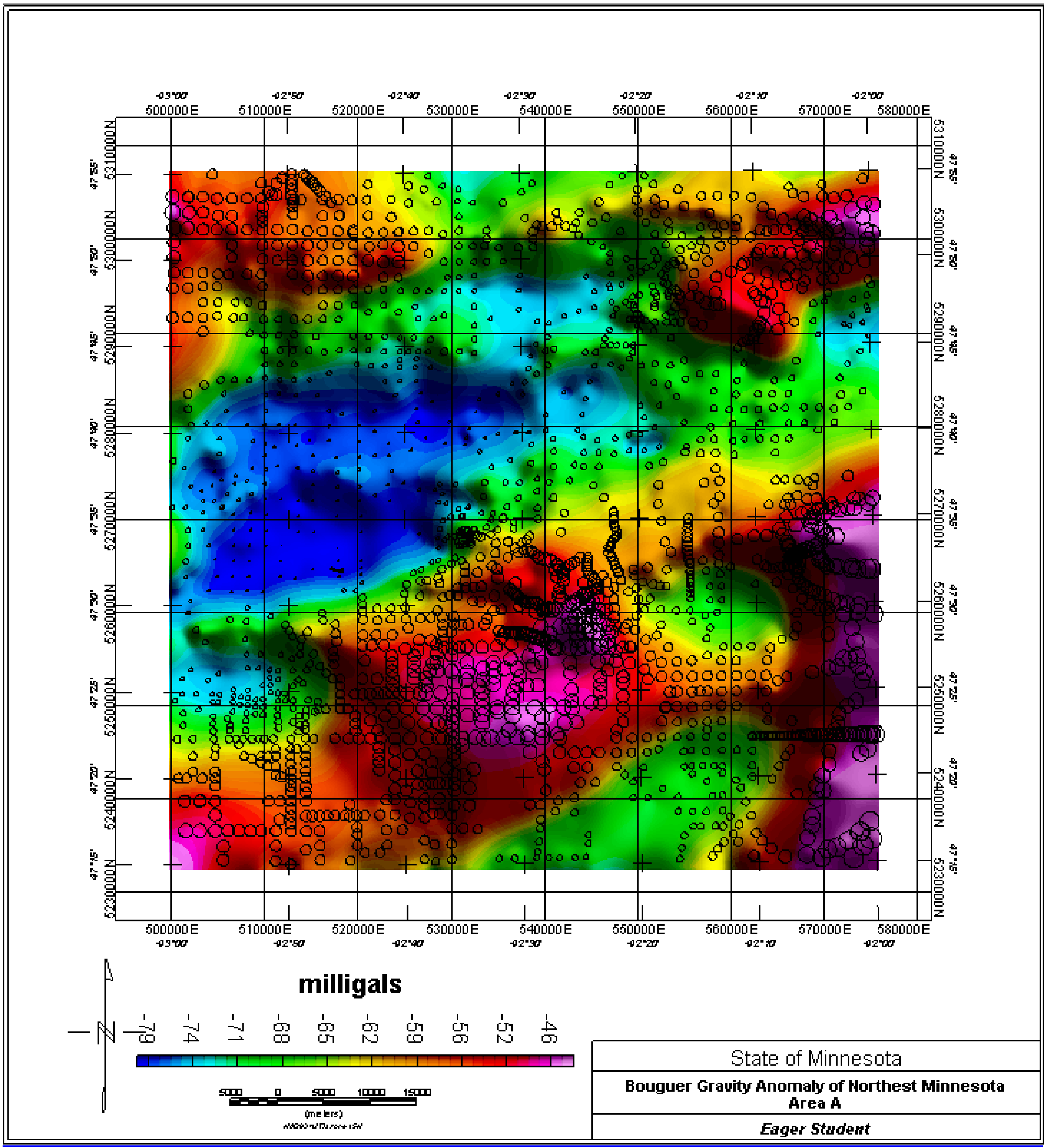
13. The rocks of the Superior Province at the northern edge of the Animikie Basin are largely intrusive granites. (a) What is the magnetic signature of these granites? (b) Explain.

14. For the aeromagnetic RTP anomalies, compute and plot (a) the pseudo-gravity anomalies. (b) Justify the assumptions underlying these pseudo-gravity anomaly estimates in the context of the available geological constraints on the magnetic anomaly sources.

Gravity Exercises

1. Grid and plot the arbitrarily distributed Bouguer gravity anomaly values in file MN_Grav_A.csv at 800-m intervals by (a) minimum curvature [Figure 1.8] and (b) inverse distance weighting [see examples in the Oasis montaj tutorial]. (c) Compare the two gridded datasets and their statistics emphasizing the relative advantages and limitations of each gridding method for qualitative and quantitative anomaly interpretation.

2. For the minimum curvature gridded Bouguer data, describe the (a) anomaly signatures and (b) possible idealized source geometries that may apply in the context of the Precambrian geology. (c) How do these Bouguer anomalies compare with the pseudo-gravity anomalies of the total field anomaly estimates of magnetic exercise 14-above. Explain the source of the differences.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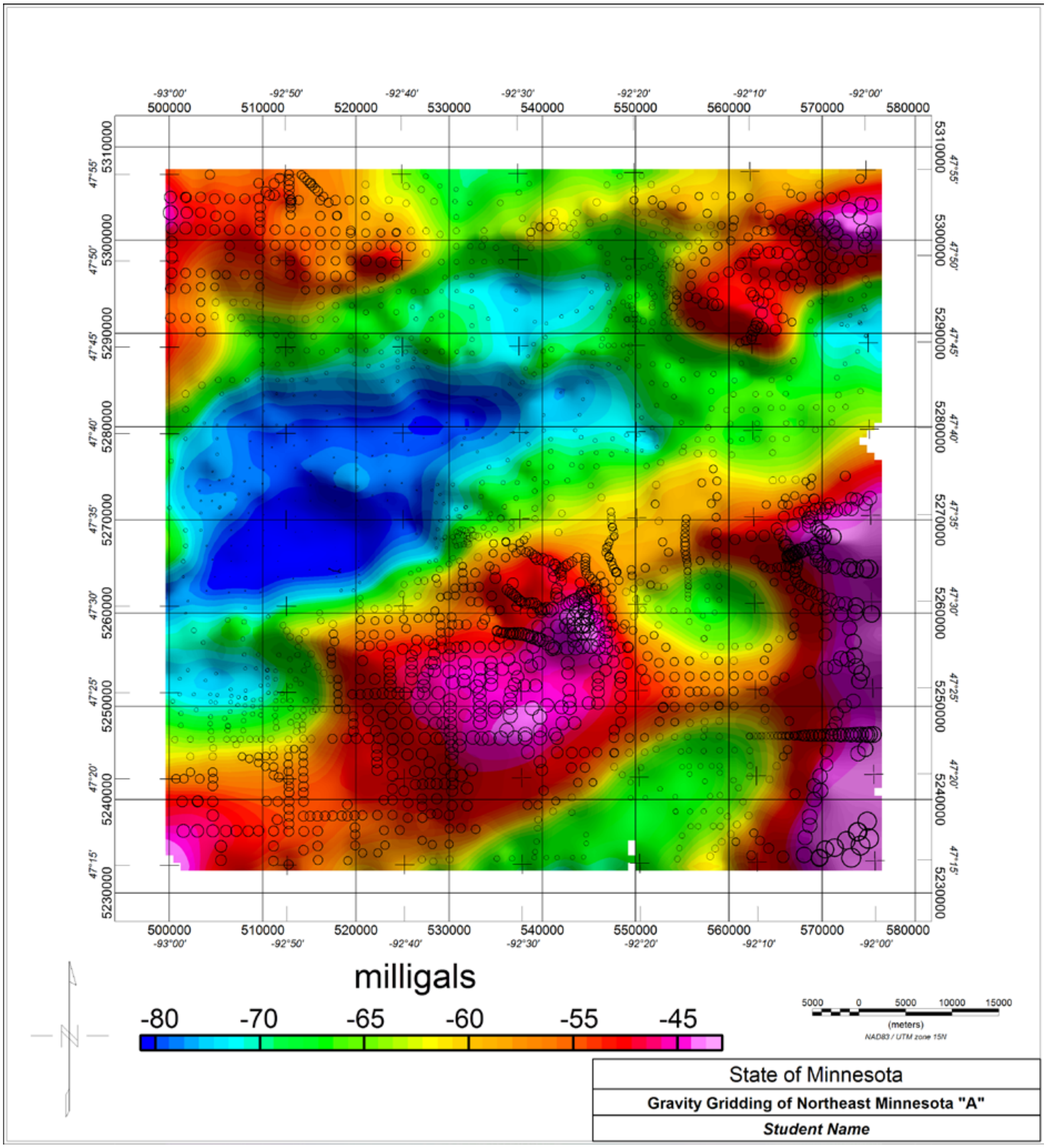

Figure 1.8: Minimum curvature gridded Bouguer gravity anomalies for study area A with superimposed station locations. The 39 × 39 anomaly array was evaluated at the ground surface with a 800-m interval.

3. Prepare shaded relief maps of the minimum curvature gridded Bouguer data sun-lit at 40° inclination from (a) the north, (b) northeast, (c) east, (d) southeast, (e) south, (f) southwest, (g) west, and northwest directions. (i) Discuss the relative advantages and limitations of these shaded relief maps for the geological interpretation of the Bouguer anomalies. (j) Are any of these maps redunant? (k) Compare their utility with the shaded relief maps of the RTP anomalies of magnetic exercise 4-above.

4. Directionally filter and plot the minimum curvature gridded Bouguer data using pass-wedges of 45° centered on the (a) north, (b) northeast, (c) east, (d) southeast, (e) south, (f) southwest, (g) west, and (h) northwest directions. (i) Compare the directionally filtered results with the shaded relief anomaly maps in magnetic exercise 3-above.

5. Plot the minimum curvature gridded Bouguer data upward continued to (a) 3, 000 m and (b) 10, 000 m. (c) Discuss the relative advantages and limitations of the continuations for the geological interpretation of the Bouguer anomalies. (c) What interpretational advantages may result from downward continuing the Bouguer anomalies?

6. Plot the minimum curvature gridded Bouguer data filtered for wavelengths roughly (a) ≥ 3, 000 m and (b) ≤ 3, 000 m. (c) How do the wavelength filtered results compare with the continuations of the anomalies? (d) Discuss the relative advantages and limitations of wavelength filtering for the geological interpretation of the Bouguer anomalies.

7. For the minimum curvature gridded Bouguer data, compute and plot (a) the horizontal first x-, (b) y-, and vertical (c) first and (d) second z- derivative anomalies, as well as the total horizontal (e) first and (f) second derivatives. (g) Discuss the relative advantages and limitations of these derivatives for the geological interpretation of the Bouguer anomalies, being specific regarding possible source depths and lateral boundaries for the anomalies of the study area.

8. For the minimum curvature gridded Bouguer data, compute and plot (a) an apparent density map. (b) Compare these results with the derivatives obtained in exercise 7-above. (c) Discuss the relative advantages and limitations of the comparison for geologically interpreting the Bouguer anomalies.

9. Using the minimum curvature gridded Bouguer data, compute and plot (a) the pseudo-magnetic anomalies. (b) How do the pseudo-magnetic anomalies compare with the bi-directionally gridded total field anomaly estimates from magnetic exercise 1-above? (c) Justify the assumptions underlying these pseudo-magnetic anomaly estimates in the context of the available geological constraints on the Bouguer anomaly sources.

10. What is (a) the gravity anomaly signature of the Animikie Basin? (b) Explain. (c) Could gravity and/or magnetic anomalies be used to map the margin of the basin?

11. Discuss (a) the origin of the Bouguer gravity anomalies over the Animikie Basin in the southern part of the study area and the Superior Province in the north. (b) What are the typical gravity anomalies over the granites and the volcanic rocks of the Superior Province? (c) Are there exceptions to these generalities? And if so, what is their origin?

12. The intrusive Duluth gabbro extends from the eastern margin of the area to approximately 92°8’W and from the southern margin to roughly to 42°35’N. (a) What is the gravity and magnetic anomaly expression of the intrusive? (b)

Explain the difference in the response to this source. (c) Which anomaly best marks the margin of the intrusive and why?

Combined Anomaly Exercises

1. From qualitative visual inspections of the bi-directionally gridded aeromagnetic total field anomalies and the minimum curvature gridded Bouguer anomalies of the respective magnetic exercise 1- and gravity exercise 1-above, (a) describe the apparent spatial correlations in the anomalies, and (b) their possible geological associations. (c) Discuss the relative advantages and limitations of the pseudo-anomalies for enhancing the anomaly correlations and their possible geological associations.

2. To facilitate quantitative analyses of the anomaly correlations, (a) evaluate and plot the first vertical derivative Bouguer gravity anomalies from gravity exercise 1.a-above at the same spatial coordinates of the RTP magnetic anomalies of magnetic exercise 3.a-above. (b) Compare these results with those of the previous exercise for identifying apparent spatial correlations of the anomalies, and their possible geological associations.

3. Plot (a) the RTP magnetic and (b) the first vertical derivative Bouguer gravity anomalies from the previous exercise normalized to a zero mean and a standard deviation of 5. (c) Discuss the relative advantages and limitations of the normalized anomalies for enhancing the anomaly correlations and their possible geological associations.

4. Sum the normalized map coefficients into Summed Local Favorability Indices [SLFI] [Section A.6.3 of Hinze et al. (2013)] and plot (a) the SLFI ≥ 3 to emphasize anomaly peak-to-peak correlations, and (b) the SLFI ≤ -3 to enhance anomaly trough-to-trough associations. (c) Discuss the relative advantages and limitations of the SLF I for enhancing the positive anomaly correlations and their possible geological associations.

5. Subtract the normalized coefficients of the first vertical derivative Bouguer gravity anomalies from those of the RTP magnetic anomalies to obtain Differenced Local Favorability Indices [DLFI] and plot (a) the DLFI ≥ 3 to emphasize magnetic anomaly peak-to-trough gravity anomaly correlations, and (b) the DLFI ≤ -3 to enhance magnetic anomaly trough-to-peak gravity anomaly associations. (c) Discuss the relative advantages and limitations of the DLFI for enhancing the negative anomaly correlations and their possible geological associations.

6. (a) How do the pseudo-magnetic and pseudo-gravity anomaly estimates from respective magnetic exercise 14- and gravity exercise 9-above compare? (b) What are the possible causes of the lack of correlation between these maps?

Study Area B

Geological background

Study area B is over the Animikie Basin south of the Mesabi Iron Range of study area A and immediately west of the Duluth Complex with boundaries as shown in Figure 1.1. It consists of a cover of Pleistocene glacially-deposited sediments overlying the sedimentary rocks of the 1.9-Ga Penokean foreland basin, the Animikie Basin.

The basal sedimentary formation is a quartzite, followed by the Biwabik Iron Formation, and the largely non-magnetic shale, greywacke, and ash beds of the Thompson Formation. The thickness of the sedimentary rocks is in excess of 3 km [Chandler, 1985]. The structure of the basin is asymmetric with low [10° to 20°] southerly dipping sedimentary rocks in the northern portion of the Basin, and steeper dips on the southern margin of the basin. Little is known about the details of the interior structure of the Basin.

Magnetic Exercises

1. Grid and plot the aeromagnetic total field anomalies in file MN_Mag_B.gdb at 200-m intervals by (a) bi-directional [Figure 1.9] and (b) minimum curvature gridding [see examples in the Oasis montaj tutorial]. (c) Compare the two gridded datasets and their statistics emphasizing the relative advantages and limitations of each gridding method for qualitative and quantitative anomaly interpretation.

2. Describe the (a) magnetic anomaly signatures of the bi-directionally gridded RTP anomaly map and (b) possible idealized source geometries that may apply in the context of the underlying geology. (c) How do the total field anomalies compare with the pseudo-magnetic anomalies of the minimum curvature gridded Bouguer gravity anomalies? (d) What is the source of the dendritic pattern of high-wavenumber anomalies? (e) Is there a change in the anomalies from north to south? Explain the change and the possible origin of the change.

3. Prepare shaded relief maps of the aeromagnetic RTP anomalies sun-lit at 40° inclination from (a) the north, (b) northeast, (c) east, (d) southeast, (e) south, (f) southwest, (g) west, and (h) northwest directions. (i) Discuss the relative advantages and limitations of these shaded relief maps for the geological interpretation of the aeromagnetic total field anomalies. (j) What information do these maps provide about the general strike of the basement rocks of the Basin?

4. Plot the aeromagnetic RTP anomalies continued 500 m (a) upward and (b) 120 m downward. (c) Discuss the relative advantages and limitations of the continuations for the geological interpretation of the magnetic anomalies.

5. For the aeromagnetic RTP anomalies, compute and plot (a) the horizontal first x-, (b) y-, and vertical (c) first and (d) second z-derivative anomalies, as well as the total horizontal (e) first and (f) second derivatives. (g) Discuss the relative advantages and limitations of these derivatives for the geological interpretation of the magnetic anomalies, being specific regarding possible source depths and lateral boundaries for the anomalies of the study area.

6. For the aeromagnetic RTP anomalies, compute and plot (a) an apparent susceptibility map. (b) Compare these results with the derivatives obtained in exercise 5-above. (c) Discuss the relative advantages and limitations of the comparison for geologically interpreting the magnetic anomalies.

7. For the aeromagnetic RTP anomalies, compute and plot (a) the pseudo-gravity anomalies. (b) How do the pseudo-gravity estimates compare with the minimum curvature gridded Bouguer gravity anomalies? (c) Justify the assumptions underlying these pseudo-gravity anomaly estimates in the context of the available geological constraints on the magnetic anomaly sources.

8. (a) Prepare a north-south RTP magnetic anomaly profile across the center of the study area. (b) Describe the changes in the magnetic anomalies across the area that are illustrated on this profile and discuss their possible source. (c) Estimate the maximum depth to the base of the Basin.

9. (a) Explain the magnetic anomaly that marks the edge of the Duluth Complex. (b) What does this suggest regarding the nature of the Complex? The magnetic anomalies of the Complex change with distance from the margin. (c) How do they change and (d) what is the source of the change?

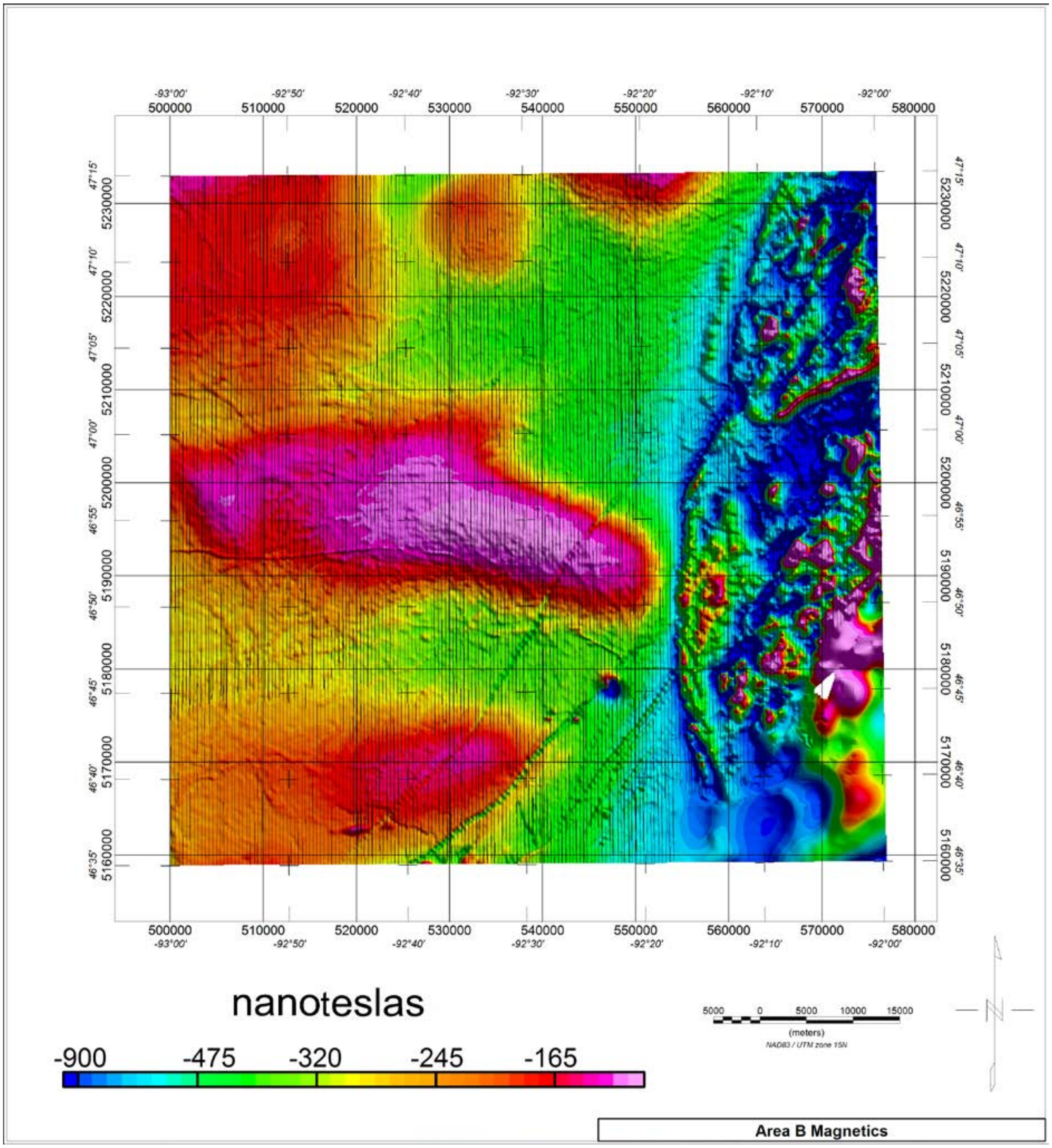

Figure 1.9: Bi-directionally gridded total field aeromagnetic anomalies for study area B with superimposed flight lines. The 400 × 400 anomaly array was evaluated at the altitude of 150 m above the ground surface with a 200-m interval.

Gravity Exercises

1. Grid and plot the arbitrarily distributed Bouguer gravity anomalies in file MN_Grav_B.gdb at 800-m intervals by (a) minimum curvature [Figure 1.10] and (b) inverse distance weighting [see examples in the Oasis montaj tutorial]. (c) Compare the two gridded datasets and their statistics emphasizing the relative advantages and limitations of each gridding method for qualitative and quantitative anomaly interpretation.
2. Describe the (a) Bouguer gravity anomaly signatures of the study area and (b) possible idealized source geometries that may apply in the context of the Precambrian geology.
3. Prepare shaded relief maps of the gridded Bouguer gravity anomaly data sun-lit at 40° inclination from (a) the north, (b) northeast, (c) east, (d) southeast, and (e) south. (f) Discuss the relative advantages and limitations of these shaded relief maps for the geological interpretation of the Bouguer gravity anomalies. Are any of these maps redundant? (g) Compare their utility with the shaded relief maps of the magnetic anomalies.
4. Directionally filter and plot the gridded Bouguer gravity anomaly data using pass-wedges of 45° centered on (a) the north, (b) northeast, (c) east, and (d) southeast directions. (e) Compare the directionally filtered results with the shaded relief maps in the above exercise.
5. Plot the gridded Bouguer gravity anomaly data continued (a) 3,000 and (b) 10,000 m upward. (c) Discuss the relative advantages and limitations of the continuations for the geological interpretation of the Bouguer gravity anomalies.
6. For the gridded Bouguer gravity anomaly data, compute and plot (a) the horizontal first x-, (b) y-, and vertical (c) first and (d) second z-derivative anomalies, as well as the total horizontal (e) first and (f) second derivatives. g) Discuss the relative advantages and limitations of these derivatives for the geological interpretation of the Bouguer gravity anomalies being specific regarding possible source depths and lateral boundaries for the anomalies of the study area.
7. For the minimum curvature gridded Bouguer gravity anomaly data, compute and plot (a) an apparent density map. (b) Discuss the relative advantages and limitations of the comparison for geologically interpreting the Bouguer gravity anomalies.
8. Using the gridded Bouguer gravity anomaly data, compute and plot (a) the pseudo-magnetic anomalies. (b) Justify the assumptions underlying these pseudo-magnetic anomaly estimates in the context of the available geological constraints on the Bouguer gravity anomaly sources.

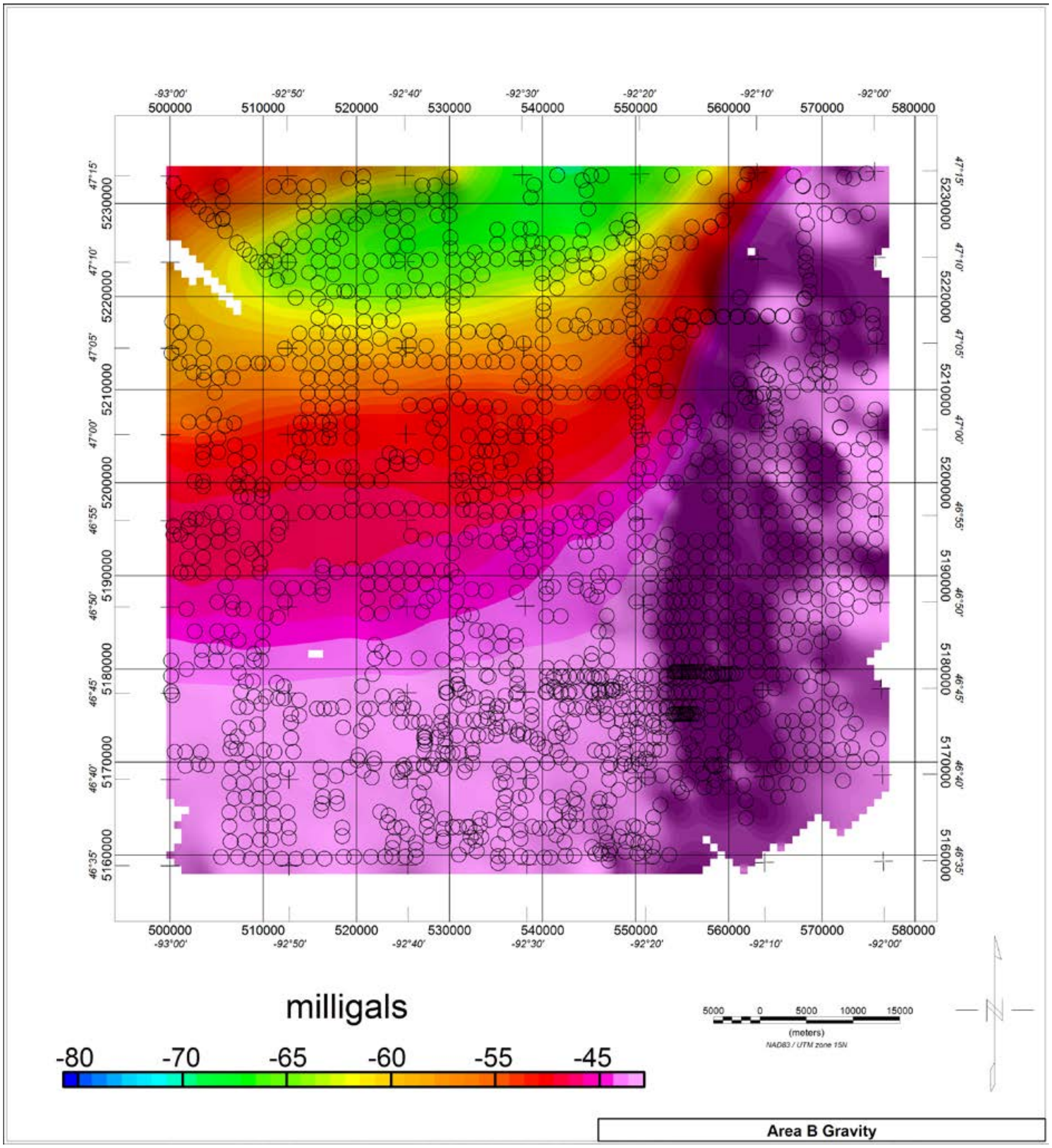

Figure 1.10: Minimum curvature gridded Bouguer gravity anomalies for study area B with superimposed station locations. The 39 × 39 anomaly array was evaluated at the ground surface with an 800-m interval.

9. The Bouguer gravity anomaly signatures of this study area do not show a strong correlation with the magnetic anomalies of the region. Explain.

10. (a) Prepare a profile of the Bouguer gravity anomalies coincident with the magnetic anomaly profile of magnetic exercise 8-above. (b) Compare the anomalies and the significance of the similarity or difference in the profiles.

11. (a) How do the gravity anomalies change from the margin of the Duluth Complex toward the East? (b) What is the significance of this change to the nature of the complex?

Study Area C

Geologic Background

Study area C is over the western margin of the St. Croix Horst of the Midcontinent Rift with boundaries as shown in Figure 1.1. It overlies the western margin of the St. Croix Horst that occurs at the northern end of the western arm of the Midcontinent Rift. The Horst consists of a basin of Keweenawan [1.1 Ga] basalt flows that have been upthrusted into juxtaposition with a broad Keweenawan clastic basin that formed over the rift upon termination of the rifting process.

The residual clastic basin, the Bayfield Basin, in the western portion of the study area is separated by high-angle thrust faults from the basaltic volcanic rocks that reach depths of approximately 10 km. The Bayfield Basin reaches a maximum depth of the order of 5 km [Allen et al., 1997]. It consists of feldspathic-to-quartzose sandstone and shale of the Hinckley and Fond du Lac formations. Faulting is common both in the St. Croix horst and in the Bayfield Basin.

Magnetic Exercises

1. Grid and plot the aeromagnetic total field anomalies in file MN_Mag_C.gdb at 200-m intervals by (a) bi-directional [Figure 1.11] and (b) minimum curvature gridding. (c) Compare the two gridded datasets and their statistics emphasizing the relative advantages and limitations of each gridding method for qualitative and quantitative anomaly interpretation.

2. Describe the (a) magnetic anomaly signatures of the bi-directionally gridded RTP anomaly map and (b) possible idealized source geometries that may apply in the context of the underlying geology. (c) How do the total field anomalies compare with the pseudo-magnetic anomalies of the minimum curvature gridded Bouguer gravity anomalies?

3. Prepare shaded relief maps of the aeromagnetic RTP anomalies sunlit at 40° inclination from (a) the north, (b) northeast, (c) east, (d) southeast, (e) south, (f) southwest, (g) west, and (h) northwest directions. (i) Discuss the relative advantages and limitations of these shaded relief maps for the geological interpretation of the aeromagnetic total field anomalies. (j) What information do these maps provide about the structure of the basaltic volcanic flows in the southeastern portion of the study area?

4. Plot the aeromagnetic RTP anomalies continued upward (a) 500 m and (b) 2, 000 m, and downward (c) 120 m. (d) Discuss the relative advantages and limitations of the continuations for the geological interpretation of the magnetic anomalies.

5. For the aeromagnetic RTP anomalies, compute and plot (a) the horizontal first x-, (b) y-, and vertical (c) first and (d) second z-derivative anomalies, as well as the total horizontal (e) first and (f) second derivatives. (g) Discuss the relative advantages and limitations of these derivatives for the geological interpretation of the magnetic anomalies, being specific regarding possible source depths and lateral boundaries for the anomalies of the study area.

6. For the aeromagnetic RTP anomalies, compute and plot (a) an apparent susceptibility map. (b) Compare these results with the derivatives obtained in exercise 5-above. (c) Discuss the relative advantages and limitations of the comparison for geologically interpreting the magnetic anomalies.

7. For the aeromagnetic RTP anomalies, compute and plot (a) the pseudo-gravity anomalies. (b) How do the pseudo-gravity estimates compare with the minimum curvature gridded Bouguer gravity anomalies? (c) Justify the assumptions underlying these pseudo-gravity anomaly estimates in the context of the available geological constraints on the magnetic anomaly sources.

8. What do the magnetic anomalies of the St. Croix horst in the southeastern portion of the study area indicate about the structure of the horst?

9. (a) What is the nature of the magnetic anomaly along the western edge of the horst and (b) what does it indicate about the faulting that marks the edge?

10. (a) Discuss the magnetic anomaly associated with the Bayfield Basin in the northwest portion of the study area and its geological significance. (b) What is the symmetry of the Basin, and (c) where is the Basin deepest?

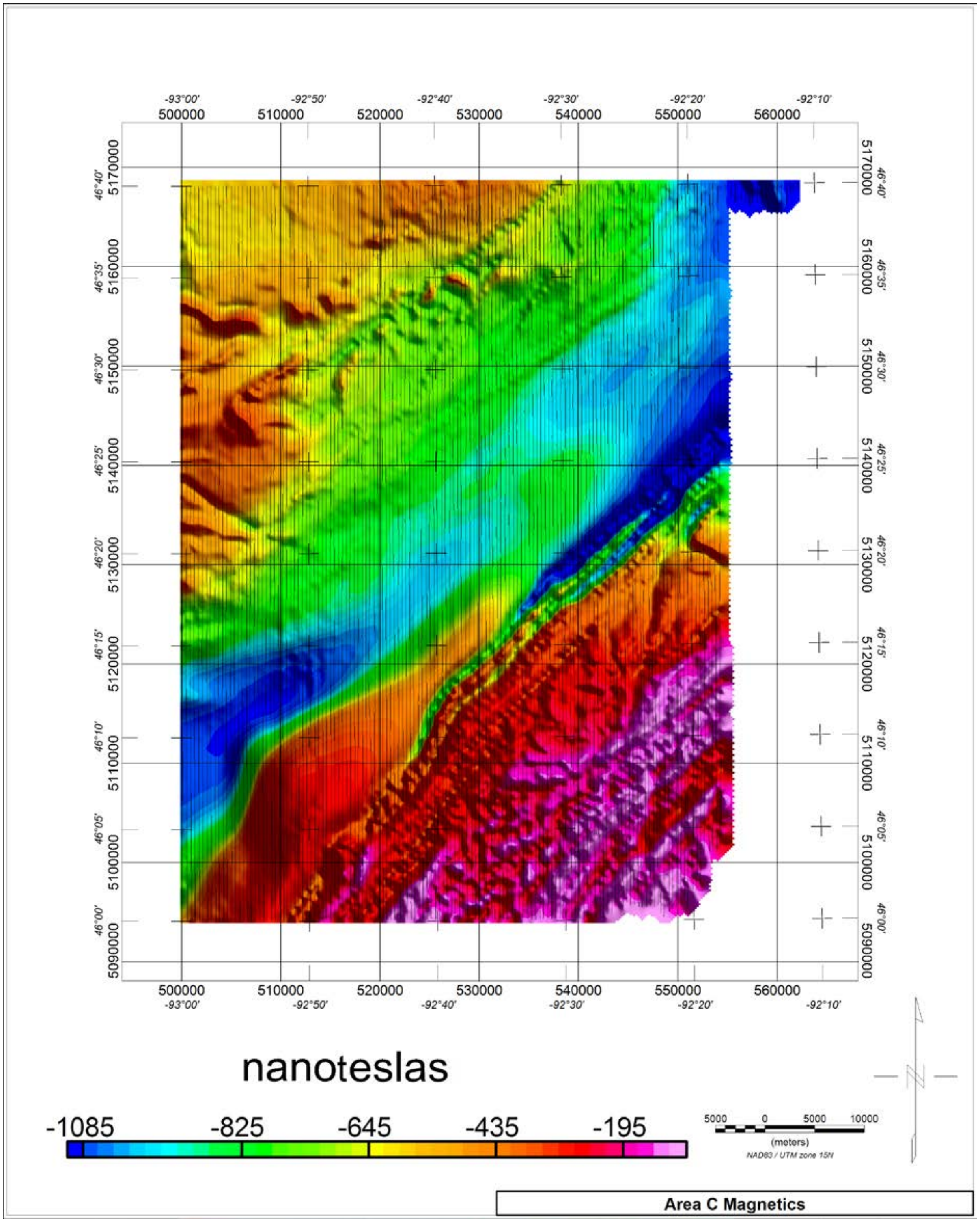

Figure 1.11: Bi-directionally gridded total field aeromagnetic anomalies for study area C with superimposed flight lines. The 400 × 400 anomaly array was evaluated at the altitude of 150 m above the ground surface with a 200-m interval.

Gravity Exercises

1. Grid and plot the arbitrarily distributed Bouguer gravity anomalies in file MN_Grav_C.gdb at 800-m intervals by (a) minimum curvature [Figure 1.12] and (b) inverse distance weighting [see examples in the Oasis montaj tutorial]. (c) Compare the two gridded datasets and their statistics emphasizing the relative advantages and limitations of each gridding method for qualitative and quantitative anomaly interpretation.

2. Describe the (a) Bouguer gravity anomaly signatures of the study area and (b) possible idealized source geometries that may apply in the context of the Precambrian geology.

3. Prepare shaded relief maps of the gridded Bouguer gravity anomaly data sun-lit at 40° inclination from (a) the north, (b) northeast, (c) east, (d) southeast, and (e) south. (f) Discuss the relative advantages and limitations of these shaded relief maps for the geological interpretation of the Bouguer gravity anomalies. Are any of these maps redundant? (g) Compare their utility with the shaded relief maps of the magnetic anomalies.

4. Directionally filter and plot the gridded Bouguer gravity anomaly data using pass-wedges of 45° centered on (a) the north, (b) northeast, (c) east, and (d) southeast directions. (e) Compare the directionally filtered results with the shaded relief maps in the above exercise.

5. Plot the gridded Bouguer gravity anomaly data continued (a) 3, 000 and (b) 10,000 m upward. (c) Discuss the relative advantages and limitations of the continuations for the geological interpretation of the Bouguer gravity anomalies.

6. For the gridded Bouguer gravity anomaly data, compute and plot (a) the horizontal first x-, (b) y-, and vertical (c) first and (d) second z-derivative anomalies, as well as the total horizontal (e) first and (f) second derivatives. (g) Discuss the relative advantages and limitations of these derivatives for the geological interpretation of the Bouguer gravity anomalies being specific regarding possible source depths and lateral boundaries for the anomalies of the study area.

7. For the minimum curvature gridded Bouguer gravity anomaly data, compute and plot (a) an apparent density map. (b) Discuss the relative advantages and limitations of the comparison for geologically interpreting the Bouguer gravity anomalies.

8. Using the gridded Bouguer gravity anomaly data, compute and plot (a) the pseudo-magnetic anomalies. (b) Justify the assumptions underlying these pseudo-magnetic anomaly estimates in the context of the available geological constraints on the Bouguer gravity anomaly sources.

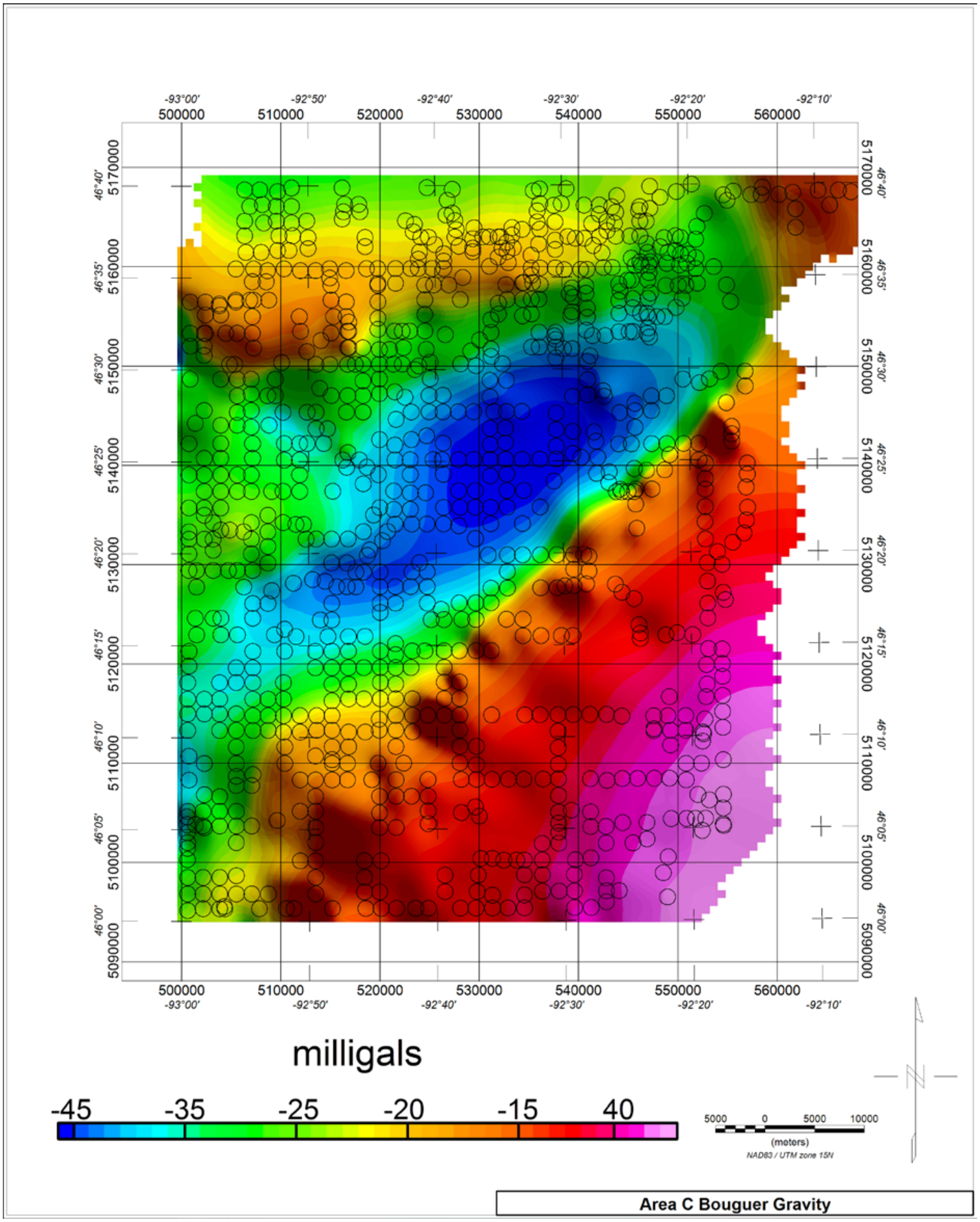

Figure 1.12:; Minimum curvature gridded Bouguer gravity anomalies for study area C with superimposed station locations. The 39 × 39 anomaly array was evaluated at the ground surface with an 800-m interval.

9. (a) Identify and describe the gravity anomaly associated with the western margin of the St. Croix horst. (b) What does this anomaly indicate about the density differential between the basalt volcanic flows and the clastic sediments of the Bayfield Basin? (c) Do any of the anomalies of the Penokean orogenic rocks west of the Bayfield Basin extend beneath the Basin? Explain.

10. (a) Compare the margin of the St. Croix Horst as indicated by the gravity and magnetic anomalies. Do they coincide? (b) Explain the possible significance of the relationship.

11. Compare the faulting as indicated by the gravity anomalies with faults interpreted from the magnetic anomalies. (b) How well do they compare? (c) What does this indicate about the relative use of the gravity and magnetic methods?

12. The gravity signatures of the Animikie and Bayfield Basins differ significantly. (a) Explain the difference and (b) discuss the significance of this difference for locating sedimentary basins.

Study Area D

Geologic Background

Study area D is over the Penokean Orogen in central Minnesota with boundaries as shown in Figure 1.1. It consists of a region of complex geology of the Penokean Orogen with several terranes of varying structure, lithology, and degree and type of metamorphism. These terranes are mapped by the nature of the magnetic anomalies and supporting rock samples. The southern portion is dominated by felsic rocks of a Penokean batholith, whereas farther north the batholith has intruded a metamorphic complex, and still farther north meta-sedimentary rocks of the Penokean fold and thrust belt are evident in the geophysical anomaly patterns.

Magnetic Exercises

1. Grid and plot the aeromagnetic total field anomalies in file MN_Mag_D.gdb at 200-m intervals by (a) bi-directional [Figure 1.13] and (b) minimum curvature gridding [see examples in the Oasis montaj tutorial]. (c) Compare the two gridded datasets and their statistics emphasizing the relative advantages and limitations of each gridding method for qualitative and quantitative anomaly interpretation.

2. Describe the (a) magnetic anomaly signatures of the bi-directionally gridded RTP anomaly map and (b) possible idealized source geometries that may apply in the context of the underlying geology. (c) How do the total field anomalies compare with the pseudo-magnetic anomalies of the minimum curvature gridded Bouguer gravity anomalies?

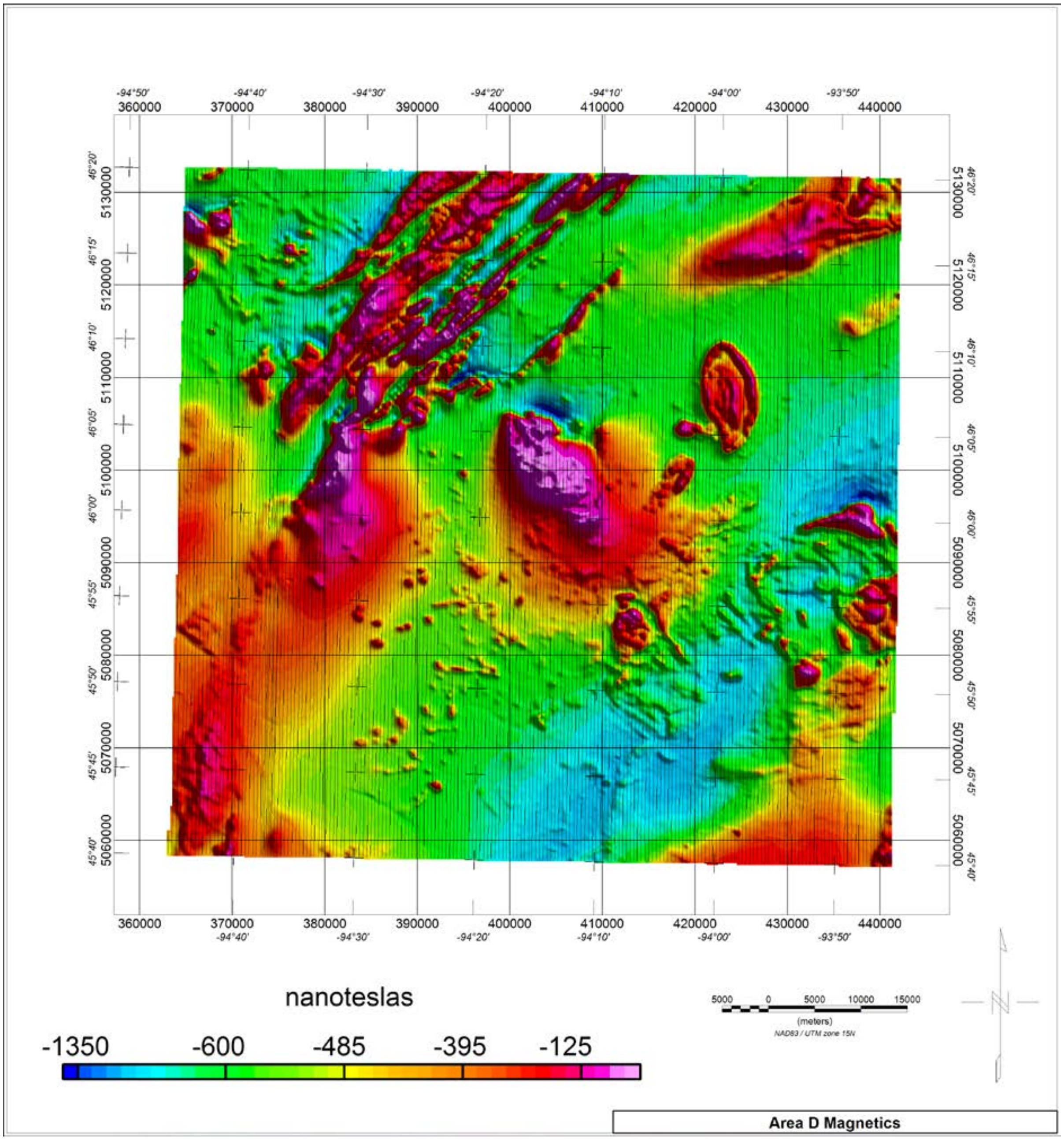

Figure 1.13: Bi-directionally gridded total field aeromagnetic anomalies for study area D with superimposed flight lines. The 400 × 400 anomaly array was evaluated at the altitude of 150 m above the ground surface with a 200-m interval.

3. Prepare shaded relief maps of the aeromagnetic RTP anomalies sunlit at 40° inclination from (a) the north, (b) northeast, (c) east, (d) southeast (e) south, (f) southwest, (g) west, and (h) northwest directions. (i) Discuss the relative advantages and limitations of these shaded relief maps for the geological interpretation of the aeromagnetic total field anomalies. (j) What anomaly pattern suggests the presence of the felsic batholith? How are the Penokean rocks of the fold and thrust belt manifested?

4. Plot the aeromagnetic RTP anomalies continued (a) upward 500 m and (b) 2,000 m and (c) 120 m downwards. (d) Discuss the relative advantages and limitations of the continuations for the geological interpretation of the magnetic anomalies.
5. For the aeromagnetic RTP anomalies, compute and plot (a) the horizontal first x-, (b) y-, and vertical (c) first and (d) second z-derivative anomalies, as well as the total horizontal (e) first and (f) second derivatives. (g) Discuss the relative advantages and limitations of these derivatives for the geological interpretation of the magnetic anomalies, being specific regarding possible source depths and lateral boundaries for the anomalies of the study area.
6. For the aeromagnetic RTP anomalies, compute and plot (a) an apparent susceptibility map. (b) Compare these results with the derivatives obtained in exercise 5-above. (c) Discuss the relative advantages and limitations of the comparison for geologically interpreting the magnetic anomalies.
7. For the aeromagnetic RTP anomalies, compute and plot (a) the pseudo-gravity anomalies. (b) How do the pseudo-gravity estimates compare with the minimum curvature gridded Bouguer gravity anomalies? (c) Justify the assumptions underlying these pseudo-gravity anomaly estimates in the context of the available geological constraints on the magnetic anomaly sources.
8. Using the similarity of anomaly trends and the character of the anomalies, delineate the major geologic terranes of the Penokean Orogen in the study area. Use both the anomaly and filtered anomaly maps in this effort.

Gravity Exercises

1. Grid and plot the arbitrarily distributed Bouguer gravity anomalies in file MN_Grav_D.gdb at 800 m intervals by (a) minimum curvature [Figure 1.14] and (b) inverse distance weighting [see examples in the Oasis montaj tutorial]. (c) Compare the two gridded datasets and their statistics emphasizing the relative advantages and limitations of each gridding method for qualitative and quantitative anomaly interpretation.
2. Describe the (a) Bouguer gravity anomaly signatures of the study area and (b) possible idealized source geometries that may apply in the context of the Precambrian geology.
3. Prepare shaded relief maps of the gridded Bouguer gravity anomaly data sun-lit at 40^{o} inclination from (a) the north, (b) northeast, (c) east, (d) southeast, and (e) south. (f) Discuss the relative advantages and limitations of these shaded relief maps for the geological interpretation of the Bouguer gravity anomalies. Are any of these maps redundant? (g) Compare their utility with the shaded relief maps of the magnetic anomalies.
4. Directionally filter and plot the gridded Bouguer gravity anomaly data using pass-wedges of 45° centered on (a) the north, (b) northeast, (c) east, and (d) southeast directions. (e) Compare the directionally filtered results with the shaded relief maps in the above exercise.

5. Plot the gridded Bouguer gravity anomaly data continued (a) 3,000 and (b) 10,000 m upward. (c) Discuss the relative advantages and limitations of the continuations for the geological interpretation of the Bouguer gravity anomalies.

6. For the gridded Bouguer gravity anomaly data, compute and plot (a) the horizontal first x-, (b) y-, and vertical (c) first and (d) second z-derivative anomalies, as well as the total horizontal (e) first and (f) second derivatives. (g) Discuss the relative advantages and limitations of these derivatives for the geological interpretation of the Bouguer gravity anomalies being specific regarding possible source depths and lateral boundaries for the anomalies of the study area.

7. For the minimum curvature gridded Bouguer gravity anomaly data, compute and plot (a) an apparent density map. (b) Discuss the relative advantages and limitations of the comparison for geologically interpreting the Bouguer gravity anomalies. (c) Does the felsic batholith show up in this map? Explain.

8. Using the gridded Bouguer gravity anomaly data, compute and plot (a) the pseudo-magnetic anomalies. (b) Justify the assumptions underlying these pseudo-magnetic anomaly estimates in the context of the available geological constraints on the Bouguer gravity anomaly sources.

9. Comparing the results of geological interpretation of both the magnetic and gravity anomalies and their various filtered maps (a) describe the relative merits of these methods in mapping the subcropping Precambrian basement rocks. (b) Illustrate with the anomalies of this study area.

10. (a) Compare the terranes mapped with the anomaly and filtered magnetic maps with the gravity anomaly maps. (b) Are the terranes also indicated on the gravity anomaly maps? (c) What is the significance of the similarities as well as the differences?

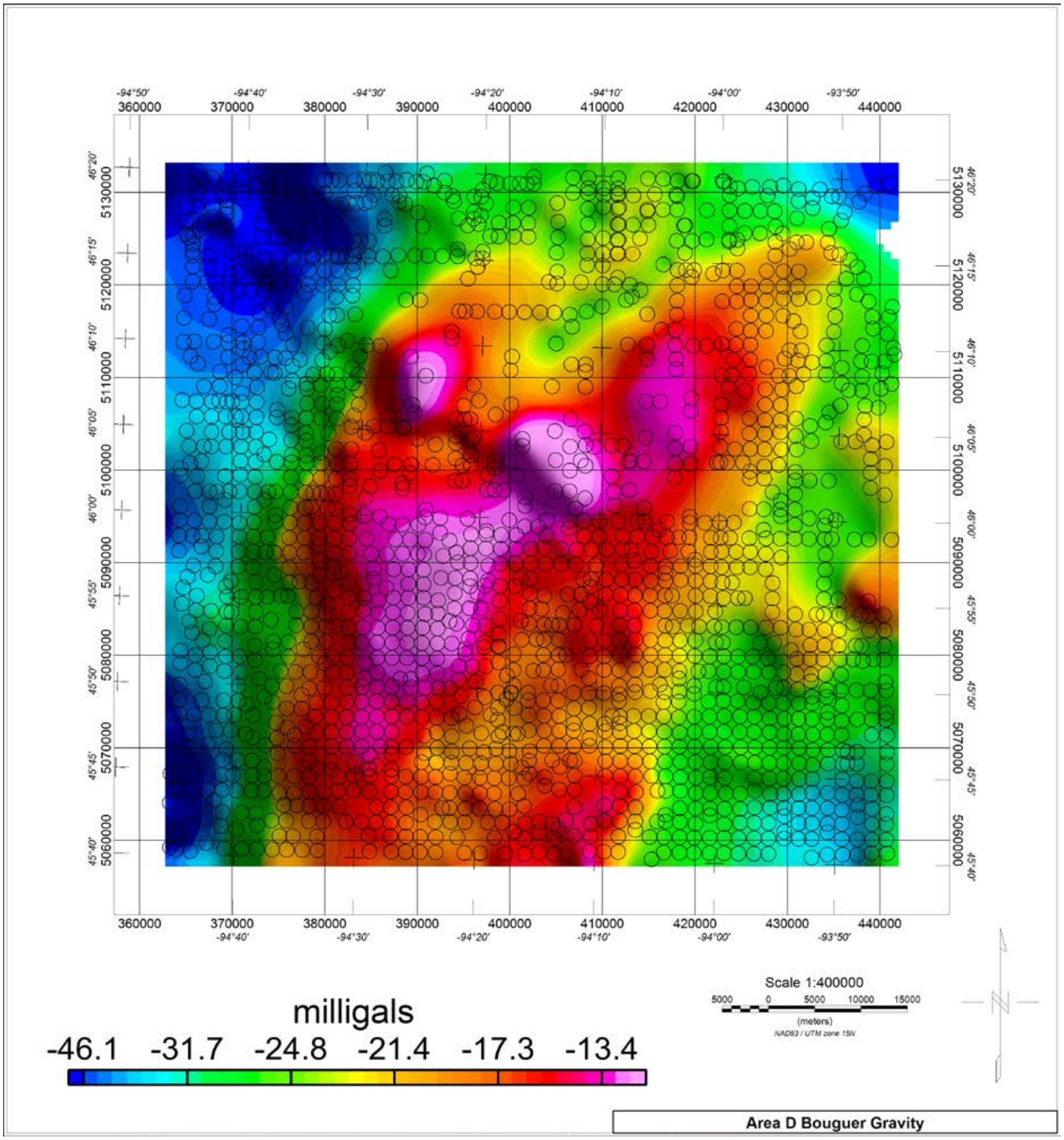

Figure 1.14: Minimum curvature gridded Bouguer gravity anomalies for study area D with superimposed station locations. The 39 × 39 anomaly array was evaluated at the ground surface with an 800-m interval.

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