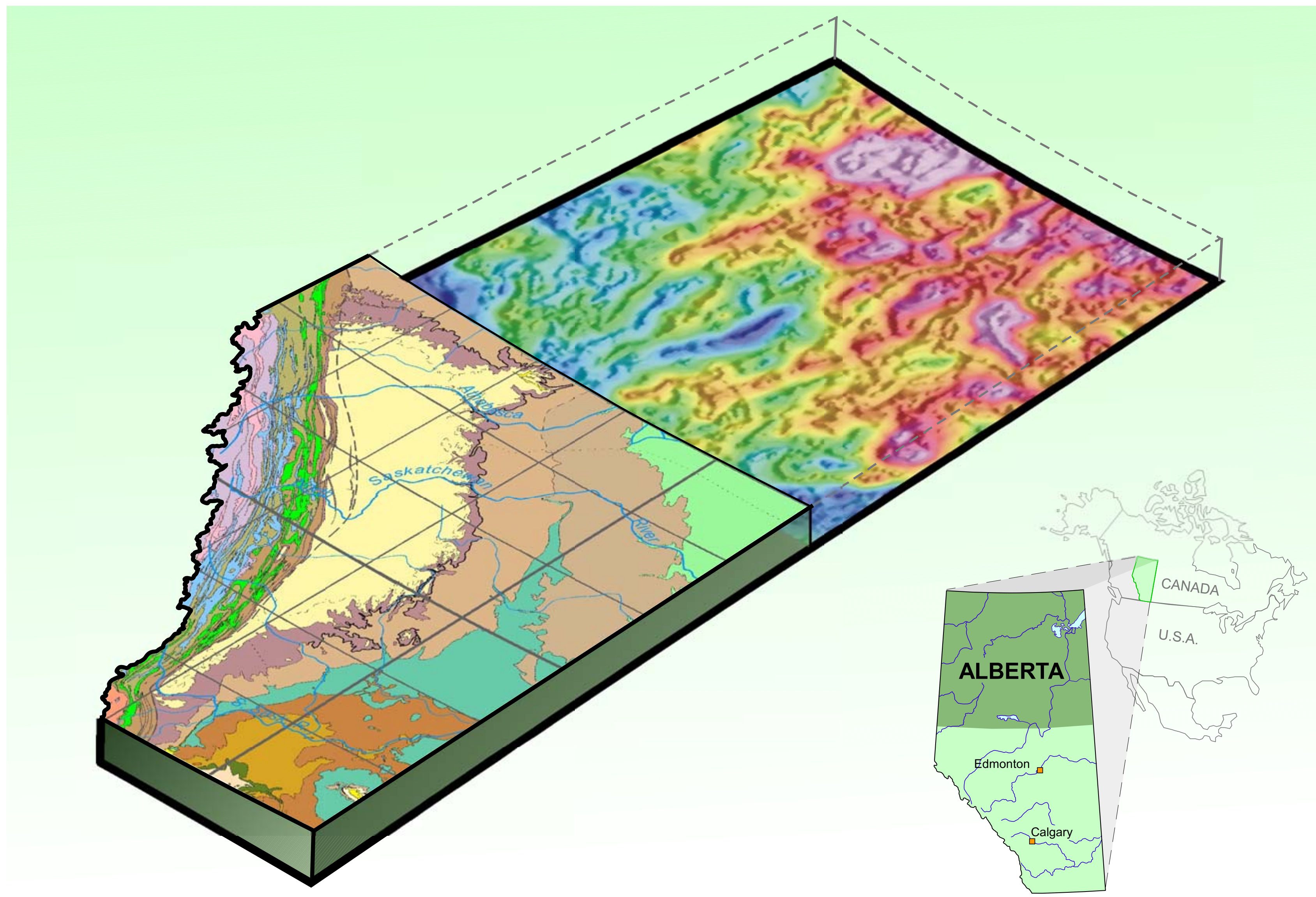
EUB/AGS Special Report 56

Catalogue of Selected Regional Gravity and Magnetic Maps of Northern Alberta



Alberta Energy and Utilities Board
Alberta Geological Survey

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Lyatsky, H.V. and Pana, D.I. (2003): Catalogue of selected regional gravity and magnetic maps of northern Alberta; Alberta Energy and Utilities Board, EUB/AGS Special Report 56.

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Published September 2003 by:
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Acknowledgments

The authors would like to acknowledge skilful assistance with the editing and reproduction of the geophysical maps by Jill Weiss. Her patience and ingenious solutions in transferring files between different software packages are highly appreciated. Natasha Blundon provided knowledgeable GIS assistance and contributed critical hints to the integration of map files into the ArcView software package. The structure of this atlas and the manuscript of the interpretive note have benefited from constructive criticism by Reg Olson. We thank Larry Lawley at Geophysical Data Centre, Geological Survey of Canada, Ottawa, for his assistance with the specifics of the data sets. Lorraine Godwin of Geosoft Inc. assisted with the provision and operation of the data processing software.

Abstract

Steep crystalline-basement faults in the Alberta and Athabasca basins are commonly expressed as potential-field lineaments. A practical tool for identifying brittle basement faults in northern Alberta was created by detailed processing of public-domain gravity and magnetic data to highlight subtle linear features. Lineaments can be gradient zones, alignments of separate local anomalies of various types and shapes, straight breaks or discontinuities in the anomaly pattern, etc.

Two fundamentally different types of crystalline-basement structure, formed in different tectonic conditions, are recognized in the cratonic, platformal Alberta Basin:

- Archean and Early Proterozoic (Hudsonian and older) ductile orogenic structures
- Middle Proterozoic to Recent cratonic ones

The latter are usually brittle, high-angle, block-bounding faults. Brittle cratonic structures sometimes follow the older orogenic ones, but commonly cut across them. Brittle block-bounding faults, far more than ancient ductile basement structures, had a controlling influence on basin evolution.

In the search for steep brittle faults in Alberta, many of the largest gravity and, especially, magnetic anomalies are undesirable because they represent the ductile, healed, ancient orogenic basement structures. These undesirable, strong anomalies commonly obscure the desirable subtle features. Steep brittle faults, formed and reactivated at different times after cratonization, are marked by potential-field anomalies that tend to be straight and very subtle. Detection of subtle gravity and magnetic lineaments was the primary purpose of making this atlas.

The common subtlety of the desirable, fault-related anomalies necessitates detailed and careful processing of potential-field data, using a wide range of anomaly-enhancement techniques and display parameters. Different processing and display methods reveal different aspects of the anomaly field. Which methods of anomaly enhancement will yield the most geologically meaningful results is often hard to predict in advance. A good practice is to process the data with a multitude of procedures and parameters. Such extensive experimentation, coupled with prior experience, helps to reveal many anomalies of practical interest.

The most geologically meaningful maps, which best highlight subtle potential-field lineaments and anomaly fabrics that could be related to faults, were selected for inclusion in this compilation. This atlas contains 17 gravity and 17 magnetic maps. Each map is accompanied by a text annotation, explaining the processing methods employed and suggesting practical uses of these maps for geological interpetation.

1 Interpretive Note on Regional Gravity and Magnetic Maps in Northern Alberta

1.1 Geological Target: Basement Faults

The cratonic, platformal Alberta sedimentary basin in the Plains of western Canada covers most of the northern part of Alberta, except for a small area in the northeast, where the sedimentary cover is absent, which belongs to the Canadian Shield. The Alberta Basin cover is Phanerozoic, whereas the crystalline rocks of the basement and the Canadian Shield are Early Proterozoic and Archean. From the sedimentary-cover zero edge, the basin deepens towards the Cordillera in the southwest, reaching the depth of many kilometres in the pericratonic foredeep.

Assistance to mineral, as well as hydrocarbon exploration, was the Alberta Geological Survey's long-range purpose in this study. The main focus was the northeastern part of the province, including the area where the crystalline basement is exposed. Many oil and gas fields in the Alberta Basin are well known to be aligned linearly. In the Precambrian Athabasca Basin in northeastern Alberta and northern Saskatchewan, fault networks may be of interest for uranium exploration. Knowledge of basement structure matters in exploration for diamonds. The large, fault-related Pine Point Mississippi Valley-type mineral deposit in the Phanerozoic sedimentary cover lies in the Northwest Territories, only a short distance north of the study area.

Two fundamentally different types of crystalline-basement structure, formed in different tectonic conditions, are recognized in the Alberta Basin:

- Archean and Early Proterozoic (Hudsonian and older) ductile orogenic structures
- Middle Proterozoic to Recent cratonic ones

The latter are usually brittle, high-angle, block-bounding faults. Brittle cratonic structures sometimes follow the older orogenic ones, but also commonly cut across them. Although anomaly signatures of the ancient ductile basement structures predominate in potential-field maps, brittle block-bounding faults had the most influence on the evolution of cratonic platformal basins.

The influence of ancient ductile basement structures on the Alberta Basin sedimentary cover is usually slight. It is largely confined to the control on Early Paleozoic depositional and drape patterns by the Precambrian erosional relief, which was formed when the future basement was exposed at the surface. This erosional basement relief is, to some extent, related to the distribution of resistant and recessive crystalline rocks, which may in turn bear some relation to the ductile, ancient structures. On the whole, studies of the Hudsonian and older ductile basement structures are of secondary value to the hydrocarbon and mineral exploration in the sedimentary cover.

Steep, brittle basement faults in the western Canadian platforms are much more subtle and less detectable than their famously huge equivalents in the spectacularly block-faulted U.S. Cordilleran foreland. Although often sub-resolution seismically, these faults and block movements nonetheless exerted considerable syn-depositional and post-depositional influence on the sedimentary cover. The basement-cover relationship is not 1:1, and basement-control mechanisms vary. The control was partial, episodic, locally variable, and commonly passive and indirect, particularly where even unreactivated brittle faults with zero offset affected fluid flow, salt dissolution and carbonate alteration. Basement faults influenced the distribution of hydrocarbon traps as well as mineralization zones in the sedimentary cover.

1.2 Geological Meaning of Geophysical Anomalies

An anomaly is the difference between the observed (measured) local value of a potential field and the field's theoretical value predicted for the same location if the earth were more laterally uniform than it actually is. Geological sources of geophysical anomalies are variations in specific physical properties of rocks, within or between rock bodies.

An anomaly indicates, indirectly, non-uniquely and with limited resolution, some perturbation in the geometric distribution of a particular physical property of underlying rocks. These physical properties are affected by the rocks' entire history as well as present state. By itself, an anomaly says nothing about its rock-made source's nature, lithology or age.

The bane of interpretation is non-uniqueness. In the physical theory, an infinite number of different sources can produce the same anomaly. For this reason, at least partial knowledge of geological targets is essential for the interpretation to be geologically realistic. Interpretation is inherently a geological procedure, in which mathematical data processing can usefully assist, but must never take the lead. No amount of computer power can replace the eye and the mind of an experienced interpreter.

1.3 Potential-Field Definition of Steep, Brittle Basement Faults

Steep, straight faults are commonly expressed as potential-field lineaments. Lineaments can be gradient zones, alignments of separate local anomalies of various types and shapes, linear breaks or discontinuities in the anomaly pattern.

In the search for steep brittle faults in the Alberta Basin, many of the largest gravity, and especially magnetic anomalies, are undesirable, as they represent the ductile, healed orogenic basement structures of Early Proterozoic and older age. These undesirable anomalies commonly dominate the potential-field maps and obscure the desirable subtle features. Steep brittle faults, formed and reactivated at different times after the cratonization of this part of North America, are associated with potential-field anomalies that tend to be very subtle. Detection of subtle gravity and magnetic lineaments, which may be related to brittle basement faults, is the primary objective of this study.

The common subtlety of desirable, fault-related anomalies necessitates detailed and careful processing of potential-field data, using a wide range of anomaly-enhancement techniques and display parameters. Different processing and display methods reveal different aspects of the same anomaly field. Which methods of anomaly enhancement and display will yield the most geologically meaningful results is often hard to predict in advance, although prior experience in the region offers useful guidance. A proper exploration and research practice is to process the data with a multitude of procedures and parameters of processing and display. Such extensive experimentation and prior experience give a chance to reveal many anomalies of practical interest.

Data processing aims to separate a useful anomaly signal from undesirable noise and to enhance the signal to make it more vivid and interpretable. A signal is the part of anomalies that contains interpretable information about the geological target of interest (basement faults, in this case). The rest is noise. The choice of processing steps depends on which aspects of the anomalies one regards as signal and aims to enhance, as well as on the results of processing experiments.

Because the signal and noise anomaly characteristics commonly overlap, complete separation between them may be impossible: either noise is retained and even enhanced, or useful signal is inadvertently altered or removed. Noise artifacts, such as Gibbs ringing or edge effects, may be introduced, contaminating the processed data. Unexpected consequences and side effects are inevitable in processing, and they often go unnoticed. Besides, it may be hard to know in advance which anomalies are desirable and which are not.

Not a panacea, data processing is a necessary evil. The best practice is to keep the processing to a minimum, avoid ill-described “black-box” techniques, and rely on mathematically simple and intuitive procedures. As much as possible, the processed and enhanced anomalies should be easy to relate back to the original anomaly shapes. Enhancement of local, low-amplitude and short-wavelength anomalies generally helps to detect the subtle gravity and magnetic lineaments.

1.4 Gravity Geophysical Exploration Methods

The physical rock property that relates gravity anomalies to rocks is density, and gravity anomalies represent lateral variations in the density of rocks.

The gravity field is attractively simple: unipolar, and almost perfectly vertical. Its measurable manifestation is acceleration due to gravity, measured commonly in Gals (1 Gal = 1cm/s^2 = 0.01 m/s^2) or milligals (1 mGal = 0.001 Gal). Bouguer gravity anomalies, used in this study, as is common practice in land areas, take account of the Earth’s rotation, polar flattening, field station’s latitude and elevation, and gravitational attraction of the rock mass lying above sea level. The gravity data for this study were supplied to the Alberta Geological Survey (AGS) and Lyatsky Geoscience by the Geological Survey of Canada (GSC) in the Bouguer reduction, but (this being a relatively flat-topography region) without a terrain correction. Bouguer anomalies are generally considered to fairly represent the rock-density variations in the crust and asthenosphere.

Gravity data in many parts of the Alberta and Williston basins are very sensitive to local vertical offsets across high-angle faults, where rocks with different densities are juxtaposed. On the other hand, high densities in some Paleozoic sedimentary rocks just above the basement may smear out the subtle gravity signatures of basement faults. For whatever reason, in the Peace River Arch in northwestern Alberta, where vertical basement-fault offsets reach tens and hundreds of metres, the associated gravity anomalies are not strong.

1.5 Magnetic Geophysical Exploration Methods

The physical rock property that relates magnetic anomalies to rocks is total magnetization, and magnetic anomalies represent lateral variations in the total magnetization of rocks. Total rock magnetization is usually complex and composite. It may consist of multiple, poorly understood remanant magnetizations of various types and vintages, as well as magnetization induced by the ambient geomagnetic field. Besides, rock magnetization is often carried by certain minerals whose distribution may have little relation to the bulk lithological and structural patterns in the rock mass. Rocks lose their ability to support magnetization when heated above the Curie temperature (575°C for magnetite). In cratonic regions, the Curie isotherm is commonly thought to lie in the lower crust or uppermost mantle (depending on the geothermal gradient and rock composition), and rocks deeper than this isotherm are not represented in the magnetic anomalies.

On a regional scale, the supra-basement sedimentary cover in the Alberta Basin is generally considered almost non-magnetic, and the anomalies are sourced overwhelmingly in the crystalline basement. Local intra-sedimentary anomaly sources may be related to depositional concentrations of magnetic minerals in some clastic rocks, or to secondary magnetization of sedimentary rocks by circulating brines.

The magnetic field itself is complex: dipolar, non-vertical. The standard unit of magnetic measurements used in exploration geophysics is nanotesla (nT). The magnetic data for this study were supplied by the GSC, with the International Geomagnetic Reference Field reduction that subtracts from the recorded magnetic values the theoretical values computed for an assumed laterally uniform earth.

The complexity (compared to gravity) of the magnetic field and of the anomaly-lithology relationships often complicates the interpretation of magnetic anomalies.

1.6 Data Coverage and Preparation

Gravity and magnetic data in northern Alberta were compiled by the GSC from surveys recorded at different times, sometimes with different parameters, technologies and specifications. However, being extremely inexpensive, these public-domain data provide excellent value for the money.

The GSC gravity-data standard of one field station per 10 km (roughly, one station per township) is usually not maintained in northern Alberta, where road access for land surveys tends to be poor. As a result, the gravity data are sparse. As an exception, a closely spaced gravity survey was conducted along the LITHOPROBE transect corridor in the southwestern part of the map area. Even with sparse gravity data, lineaments longer than several field-station intervals, as many fault-related anomalies are, can be detected with careful anomaly-enhancement processing. Although the focus of this study is northeastern Alberta, contiguity of the gravity data enabled us to process these data for all of northern Alberta, from the British Columbia (120°W longitude) to the Saskatchewan (110°W) borders. Subject to AGS requirements, the map area was continued in the south to the 55°N latitude, and in the north to the Northwest Territories border at 60°N.

Detailed, good quality regional aeromagnetic data are available from the GSC in northeastern Alberta, especially north of the 58°N latitude where two large regional surveys are merged. The flight lines are east-west. A small gap in the coverage exists over parts of Lake Athabasca, near the map area’s eastern boundary, north of 59°N.

A very large gap in the northern Alberta GSC magnetic data occurs west of the 114°W longitude. In some areas to the west of that gap, in north-central and northwestern Alberta, extreme sparseness of the available aeromagnetic data causes gridding problems and severely degrades the anomaly definition. To maintain coherent coverage across the map area, and because northeastern Alberta is the primary focus of AGS interest, the magnetic map area was restricted to longitudes 110°-114°W (i.e., fourth to fifth meridians), between latitudes 55°N and 60°N.

Bouguer gravity values decline gradually to the southwest as the Alberta Basin deepens. Because the depth to magnetic-anomaly sources in the basement increases with basement depth, the shortest-wavelength magnetic anomalies are found in the northeastern corner of Alberta, where the basement is exposed at the surface or is very shallow.

Gridding of the data has to be tight enough to capture the anomaly details where the field data were recorded at a close spacing, without needlessly creating enormous data files that may slow down the processing. In a large region where survey parameters vary from one area to another, a compromise grid-cell size needs to be chosen, adequate for areas of both detailed and sparse field surveys. For the gravity data, optimal grid-cell size was chosen to be 1000 m, for the magnetic data, 400 m.

Gridding does not substitute for sparse survey coverage, and it may create artifacts of its own. Subtle artifacts around some of the sparse gravity field stations, in particular, become more pronounced when anomaly enhancement is applied. In magnetic data, variations in the anomaly wavelength content may be related to variable survey parameters (such as flight-line spacing and altitude), as well as to variations in basement depth, structure and composition. False magnetic lineaments can be created along the boundaries of dissimilar surveys merged into a common dataset. Imperfect flight line levelling of aeromagnetic data sometimes causes east-west corrugation in the anomaly-enhanced derivative maps.

1.7 Processing of the Data to Highlight Lineaments

Processing of geophysical data depends on the anomaly characteristics and on the specific geological needs of interpretation. Its aim is to highlight and enhance those anomalies that reveal information about the geological target. In this study, the target is high-angle basement faults, and their potential-field signatures are known to commonly be subtle lineaments.

Many anomaly-enhancement methods were experimented with in the production of this atlas, and many maps were generated as a result. Of those numerous processing products, only the most geologically meaningful ones were selected for inclusion. This section describes the methods used to produce the maps included in this atlas, and explains the reasons for their selection. The Geosoft data processing package was used for the computations and initial display. The selected maps were then exported into the ArcView format to meet the AGS standards. With many methods of data processing and display, the number of possible derivative maps is almost endless, and this selection represents nothing more than a reasonable sample.

Specific processing methods used to produce each map are described in the text annotations included with the maps, as well as in the subsections below. Detailed mathematical descriptions of the processing methods can be found in Geosoft manuals and in most geophysics textbooks.

1.7.1 Reduction of Short Wavelength Noise

Short wavelength noise in the data, such as gridding artifacts or flight line corrugation, may interfere with geologically meaningful lineaments. Cultural magnetic noise is caused by man-made infrastructure. Glacially transported erratic rocks from the Canadian Shield sometimes create undesirable, if slight, magnetic anomalies, as does removal of glacial till (if it is magnetic) by river incision. Aliasing may give false shapes to under-sampled anomalies.

Anomaly enhancement that boosts subtle and short wavelength anomalies also boosts the short-wavelength noise. This noise should therefore be suppressed before anomaly enhancement is applied. Unfortunately, such noise suppression may have a price of sacrificing some components of useful anomalies.

Bandpass wavelength filtering has several drawbacks: it requires assuming the cut-off wavelengths, can smear the separation due to non-vertical filter roll-off, and can contaminate the data by Gibbs ringing. Noise suppression can also be achieved by upward continuing the data by one or two grid-cell sizes, or by application of smoothing convolution filters. By experimentation, upward continuation (usually by one cell size) was found to be the most effective for the gravity data in the study area, and two passes of the Hanning convolution filter for the magnetic data.

1.7.2 Horizontal-Gradient Maps

Horizontal-gradient maps are vivid yet simple and intuitive derivative products to reveal the anomaly texture of potential-field maps and to highlight discontinuities in the anomaly pattern. Horizontal-gradient maxima occur over the steepest parts of potential-field anomalies, and horizontal-gradient minima over the flattest parts. Short wavelength anomalies are enhanced. More than vertical-gradient or analytic-signal maps, horizontal-gradient maps are very intuitive, as they can easily be related to the original potential-field anomalies. If an anomaly map is thought of as a relief, then a horizontal-gradient map contours the steepness of the anomaly relief's slope.

The horizontal gradient is computed by (1) computing the partial directional derivatives of the mapped dataset in two mutually orthogonal directions; (2) squaring the resulting values for each grid node; (3) adding the squares; and (4) taking the square root of the sum. Remarkably, even with the comparatively sparse gravity data in the Alberta and Williston basins, experience shows that horizontal-gradient gravity maps are one of the very best tools for the detection of basement faults (Figure 1).

1.7.3 Vertical-Gradient (Vertical-Derivative) Maps

Vertical-derivative (vertical-gradient) maps accentuate short wavelength components of the anomaly field, while de-emphasizing long wavelength components. The vertical gradient can be thought of as the rate of change of anomaly values as the potential-field data are upward continued. Such maps are not intuitive, and they may be harder than horizontal-gradient maps to relate to the original anomaly shapes. Nonetheless, vertical-gradient maps are useful tools for highlighting the details of anomaly texture, as well as the discontinuities and breaks in the anomaly pattern.

The vertical-gradient procedure was found to be effective for the enhancement of magnetic anomalies. The gravity data, on the other hand, were found to be too sparse in northern Alberta to greatly benefit from such processing, which boosted the gridding artifacts. Only the magnetic vertical-derivative map was included in this atlas.

1.7.4 Total-Gradient (Analytic-Signal) Maps

Total-gradient (or analytic-signal) maps highlight subtle anomalies and discontinuities in the anomaly pattern. Short wavelength anomalies are enhanced. Total-gradient maps are not entirely intuitive because they incorporate the vertical derivative, and they may be harder than horizontal-gradient maps to relate to the original anomaly shapes.

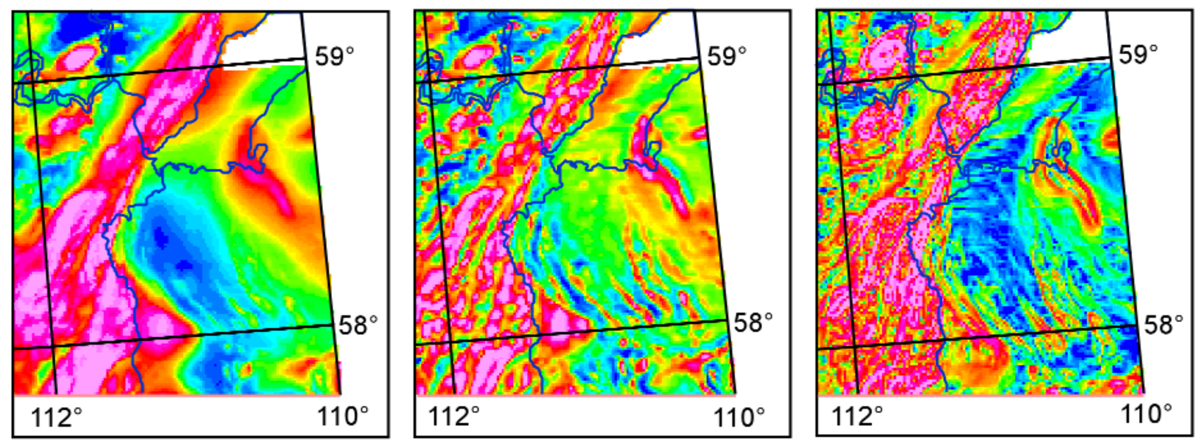
The total gradient is computed by (1) computing the partial horizontal derivatives of the mapped dataset in two mutually orthogonal directions; (2) computing the vertical gradient of the mapped dataset; (3) squaring the resulting partial-gradient values for each grid node; (4) adding the three squares; and (5) taking the square root of the sum.

1.7.5 Automatic Gain Control

To highlight local anomaly details, automatic gain control (AGC) boosts amplitudes in areas with smooth anomalies. Without sacrificing the long wavelength information, such enhancement of the local anomaly "relief" usefully sharpens subtle breaks in the anomaly pattern (Figure 1).

Gain is estimated with a sliding square filter window, centred on each grid node in turn. Experimentation helps to determine the optimal window size for each particular dataset. A maximum gain correction is specified to prevent the procedure from blowing up in the areas of low signal. Anomalies with the wavelength exceeding the window size are comparatively little affected by the AGC calculation, whereas anomalies equal to or smaller than the window are affected strongly.

Local (as opposed to regional) AGC was found, by experimentation, to be particularly effective for the magnetic data in the study area. The gravity data were found to be too sparse and lacking short wavelength



a) Total field magnetic map

b) Magnetic map with amplitude gain control

c) Horizontal gradient magnetic map

Figure 1. Magnetic anomaly enhancement through data processing; shear zones locally known to be associated with uranium mineralization in the sub-Athabasca basement are almost unnoticeable on the total field magnetic map (a), but are much better defined by local anomaly-amplitude gain control (b), and subtle breaks in the anomaly pattern are revealed by the horizontal gradient map (c).

components for AGC to be useful. Inside the filter window centred at each position, the best- fit plane is calculated, which minimizes the RMS (root-mean-square) misfit with the data. The average RMS difference between the data and plane values within the window is the local signal gain. Signal at the grid node in the centre of the window is the difference between the data value and the plane value at that position. The first pass over the grid determines the signal and gain for each position, and records the largest (maximum) gain encountered. In the second pass, the signal at each position is multiplied by the ratio of maximum to local gain, not exceeding the specified maximum correction. The new, gained signal is then added to the original background value to obtain the final signal value.

1.7.6 Regional-Local Anomaly Separation

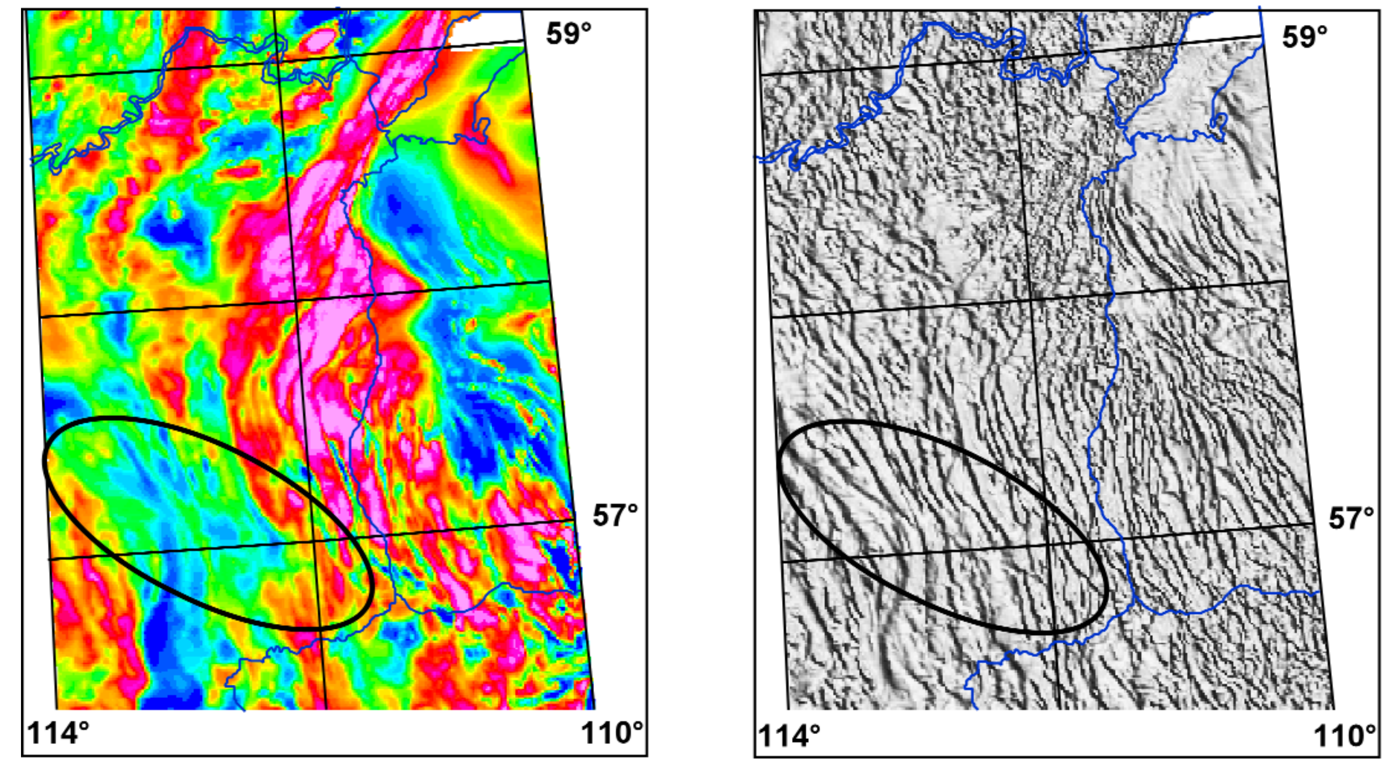
To highlight local anomalies, the regional component of the gravity or magnetic anomaly field is commonly subtracted from the data, generating a residual map. The definition of regional vs. local anomaly field is inevitably subjective. Regional-local separation can be achieved by bandpass wavelength filtering, but that procedure requires assuming the cut-off wavelengths, can smear the separation due to non-vertical filter roll-off, and can contaminate the data by Gibbs ringing. A more intuitive alternative is to compute from the gridded data the best-fit smooth surface, of a selected low order, and then remove that smooth surface as the regional component.

A best-fit surface of too low order may leave behind too much of the regional field. An order too high may cause the desirable local anomaly components to be removed. Good results in the western Canadian platforms, including this area, are often obtained by computing and subtracting from the data a third order, best-fit surface. Gravity data benefited from this procedure the most, whereas no significant improvement was obtained for the magnetic data.

1.7.7 Shadowgrams (Shaded-Relief Maps)

Shadowgrams reveal variations in the dominant anomaly wavelengths and trends between regions. The computational procedure treats a potential-field map as a relief, and computes the shadow pattern that would be created if this relief were illuminated by the sun from a user-specified angle (Figure 2).

The effect is analogous to taking aerial photographs of a terrain illuminated by the sun. Subtle, local and short wavelength anomalies are emphasized. Sidelighting (illuminating from a non-vertical angle) acts as a directional filter, highlighting anomalies oriented at high angles to the "sun" azimuth and suppressing azimuth-parallel anomalies. Such a directional bias is avoided in shadowgrams computed with a vertical sun angle, and a vertical shadowgram simulates a horizontal-gradient map (steepest gradients are darkest). Vertical shadowgrams are vivid when plotted on their own or as layers on top of colour-coded potential-field maps.



a) Total field magnetic map

b) Shadowgram with illumination from SW

Figure 2. Magnetic anomaly enhancement by side-lighting; the potential-field magnetic data are processed as a digital elevation model and illuminated from a user-specified azimuth and inclination. In this example, a previously unknown likely basement structural feature is revealed by sidelighting near Fort McMurray, northeastern Alberta.

Although vertical shadowgrams are analogous to horizontal-gradient maps, no 1:1 identity is to be expected between them. These two computational procedures are dissimilar in their nature and treatment of the data, and the differences are greatest if the data are sparse. The output data grids may contain dissimilar local details and dynamic ranges, and they are plotted with different display parameters. Similar anomalies may thus be enhanced and highlighted differently. Besides, various methods may be used to compute the horizontal gradient, with dissimilar results. Beneficially for interpretation, vertical shadowgrams and horizontal-gradient maps are not redundant but complementary. In highlighting similar anomaly shapes and patterns, they reveal different information.

Sidelighting, with its directional bias, loses anomalies parallel to the "sun" azimuth, and many shadowgrams with various sun angles need to be generated for each dataset to reveal variously oriented anomalies.

The optimal "sun" inclination for the northern Alberta gravity data was found, by experimentation, to be 45° from the horizon, and for the magnetic data 30°. With these inclinations, sweeps of shadowgrams were generated for the gravity and magnetic data, with the "sun" illumination from the north, northeast, east, southeast, south, southwest, west and northwest.

1.7.8 Upward-Continued Maps

The large-scale regional anomaly pattern is revealed by upward continuation. Comparing upward-continued data with the raw data shows which of the anomalies survive the filtering, and thus can be inferred to probably have big rock sources. The anomalies that do not survive upward continuation lack long wavelength components and (presumably) large and massive sources. Principal orientation of geological features in the crust is revealed by the orientation of potential-field anomalies in upward-continued maps.

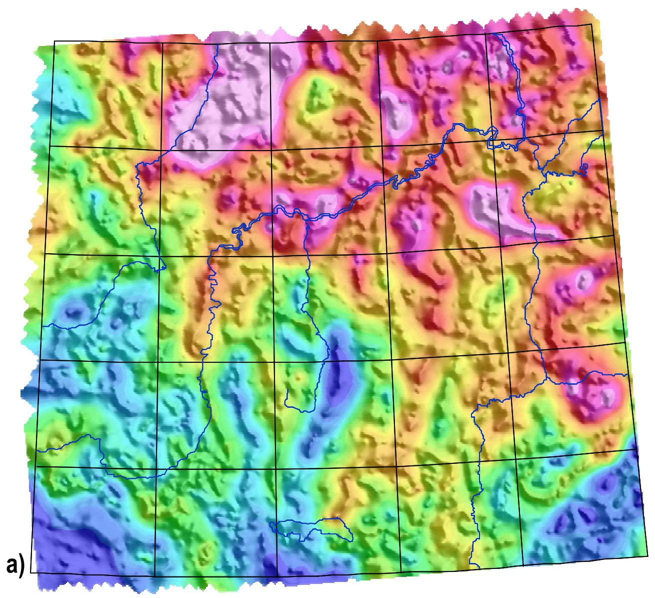
This procedure uses wavelength filtering to simulate the appearance of potential-field maps if the data were recorded at a higher altitude than they actually were. For example, land data can be filtered to calculate what the same map would look like with the data flown at a user-specified high altitude. Short wavelength anomalies are suppressed preferentially, while anomalies with a significant long wavelength component remain. The fundamental assumption that no anomaly sources exist between the real and simulated (nominal) recording levels holds reasonably well in the Canadian Plains, especially when the nominal recording level is taken to be very much higher than any topography.

Upward continuation is more intuitive than bandpass wavelength filtering and less artifact prone. The bulk structure of the upper crust (where the brittle faults reside, above the brittle-ductile transition) is often revealed by upward-continuing potential-field data to a nominal altitude of around 20 km. Because the gravity data in northern Alberta are sparse, and thus have a diminished short wavelength component to begin with, best results were obtained with upward continuation to only 15 km. A 20-km nominal altitude was found to be effective with the magnetic data.

1.8 Detection of Subtle Lineaments in Processed Maps

Visual identification of lineaments is the most reliable when done by an experienced interpreter familiar with both the geological targets and the local specifics of the anomaly field. Automatic anomaly-identification techniques do exist, but they rely on advance parameterization of desirable anomalies that may be too rigid to generate the most geologically meaningful anomaly picks. A good visual method to identify subtle lineaments in anomaly-enhanced derivative maps is to view these maps at a low angle on a table, as one would sometimes view a seismic section. Rotating the map on the table, to change the interpreter's viewing direction, reveals lineaments and anomaly breaks with a variety of orientations. Viewing a map from above helps to see the distribution of anomaly patterns and domains (Figure 3).

a)



b)

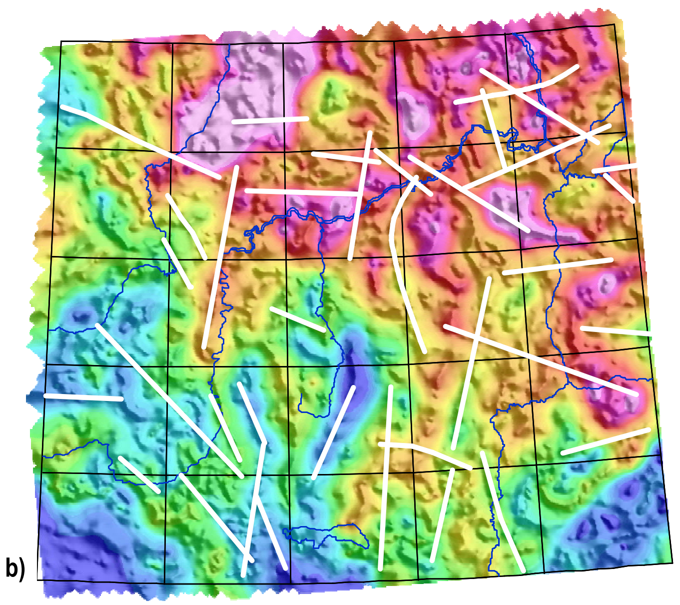


Figure 3. (a) Bouguer gravity map with vertical sun-angle shadowgram; (b) same map with interpreted lineaments.

Particularly valuable, but hard to detect, are the aligned slight disruptions of an otherwise consistent anomaly field. Because brittle cratonic faults commonly run through the ancient ductile basement structures without causing significant offsets, such razor-sharp but extremely subtle disruptions of the anomaly pattern are a prime target for interpretation. More vivid discontinuities, across which the overall anomaly pattern noticeably changes, may be related to the ancient ductile structures. These large discontinuities should be noted, nevertheless, because some of the large brittle structures are aligned with large ductile ones.

Any linear potential-field feature that runs for hundreds of kilometres, across large parts of the study region, is of interest. Such straight trans-regional features commonly represent major crustal shear zones and faults of various types and ages. The potential-field manifestation of a fault may vary along its trend, as it depends on the specific anomaly sources the fault runs through or past. An alignment of discontinuous, multiple local anomalies should therefore be of interest to the interpreter, because such alignments may represent 'desirable' faults.

2 References

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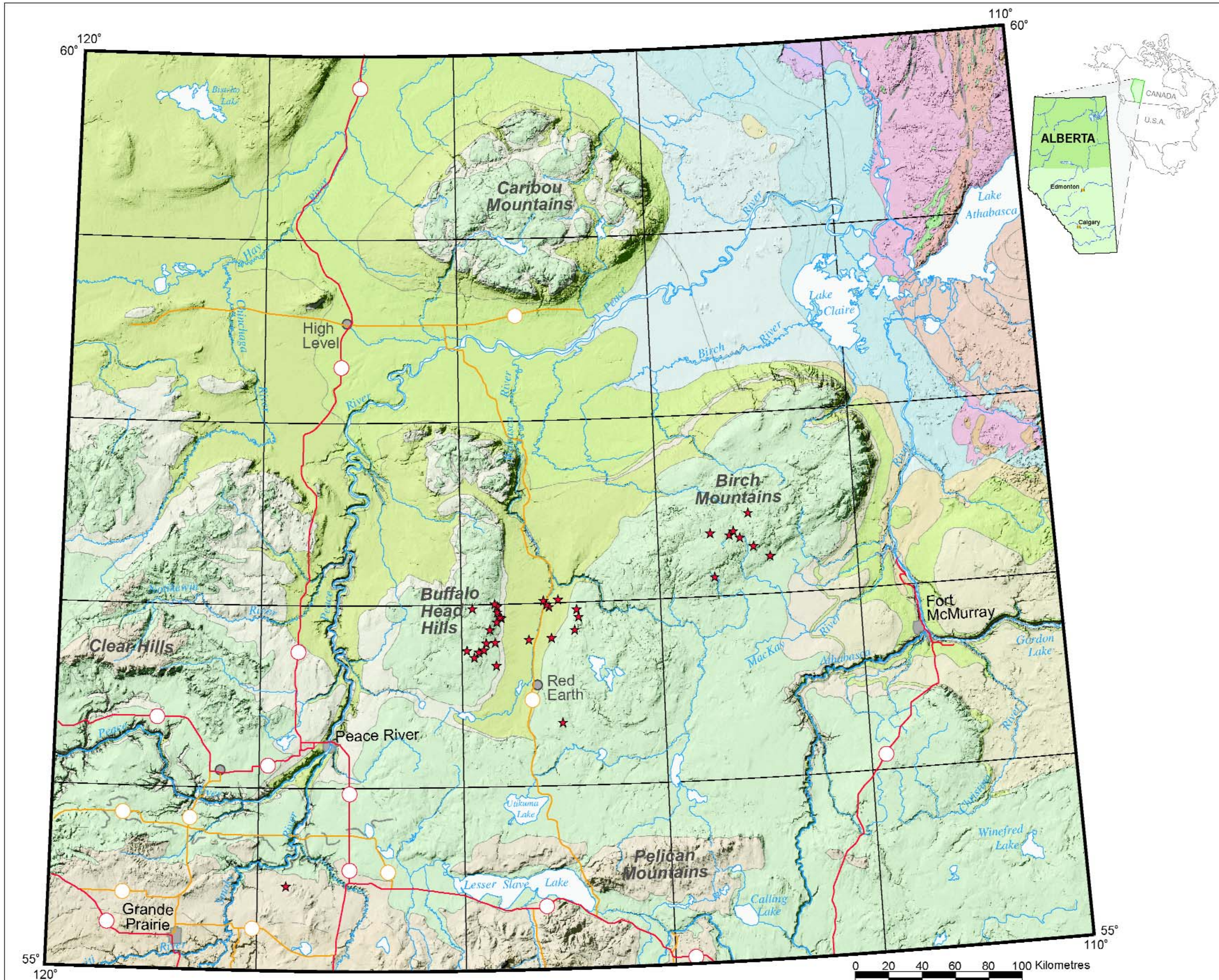
Sprenke, K.F., Wavra, C.S. and Godfrey, J.D. (1986): Geophysical expression of the Canadian Shield in northeastern Alberta; Alberta Research Council, Alberta Geological Survey, Bulletin 52, 54 p.



Cretaceous

- Wapiti Group
- Dunvegan Formation
- Shaftesbury Formation
- Smoky Group, Kaskapaw and Puskwaskau formations
- Pelican Formation
- Joli Fou Formation
- Grand Rapids Formation
- Clearwater Formation
- McMurray Formation

★ Kimberlites**

Devonian

- Upper Devonian Formation
- Middle Devonian Formation

Early Protozoic

- Athabasca Group

Archean to Early Protoerozoic

- Low-grade metasedimentary rocks
- Early Proterozoic granitoids
- High-grade metasedimentary rocks
- High- to low-grade mylonite

Notes:

*The 3-D Digital Elevation Model (DEM) of the Northern Alberta is created using Arc/Info Grid software. The sun azimuth and angle of the image are set at 315° and 45° respectively, with a 4 times vertical exaggeration. The original dataset was obtained from Geomatics Canada with the regular grid spacing at 3 arc seconds. Projection of the DEM is 10 degree Transverse Mercator with the central reference meridian at 115° N and datum at NAD83.

**To January 2003, 47 kimberlitic pipes have been discovered in three separate areas of the northern Alberta:

- Mountain Lake cluster: 2 pipes discovered in 1989-1990 by Monopros Limited (the then Canadian subsidiary of De Beers)
- Buffalo Head Hills field: 37 pipes (29 are diamondiferous) discovered between 1997 and January 2003 by Ashton Mining of Canada Inc., in a joint venture with EnCana Corporation and Pure Gold Resources Ltd.
- Birch Mountains field: 8 pipes, which includes 7 pipes discovered in 1998 by Kennecott Canada Exploration Inc., Montello Resources Ltd. and Redwood Resources Ltd., and 1 pipe discovered in December 2000 by New Blue Ribbon Resources Ltd.

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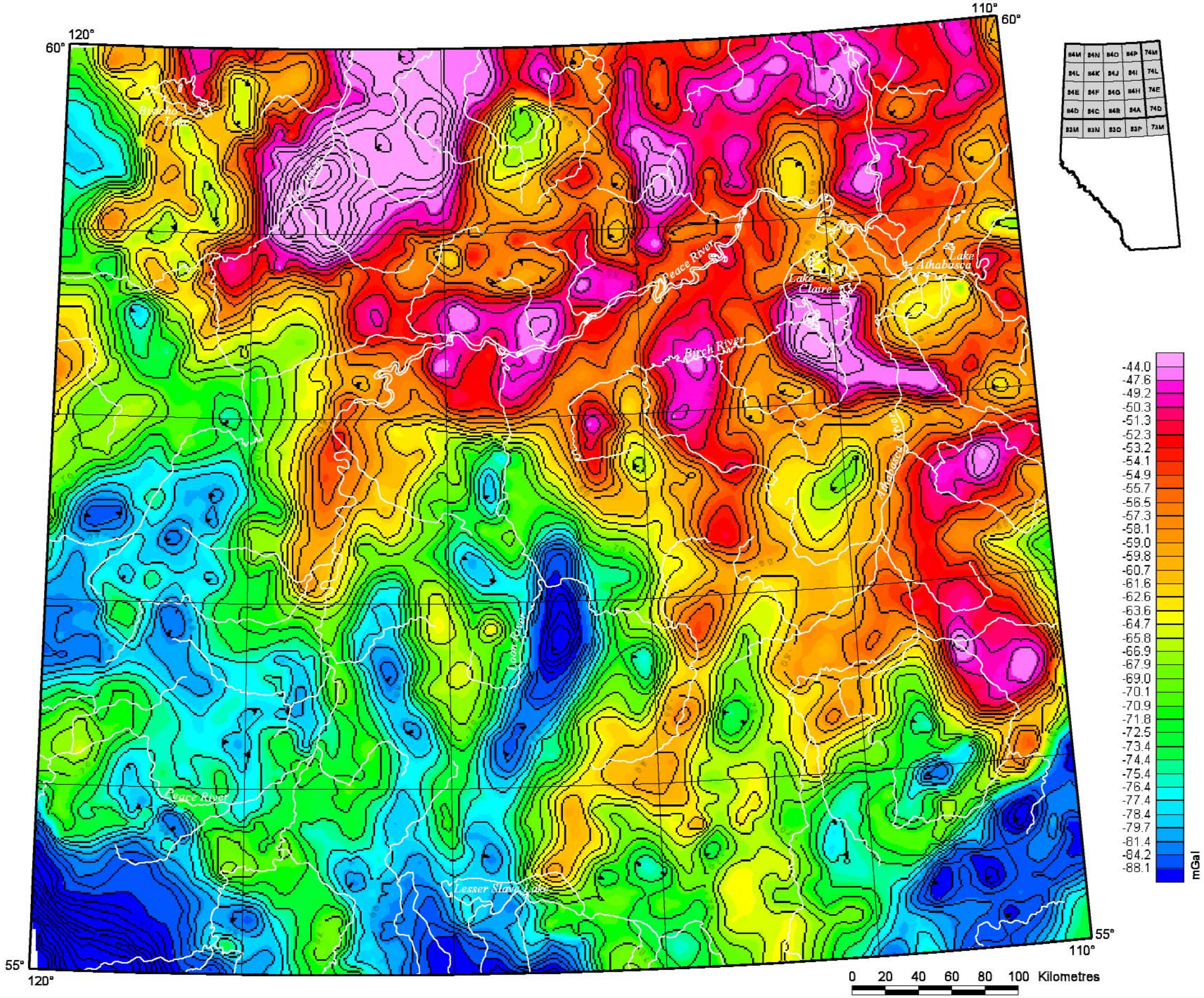
Map 1. Bedrock geology of northern Alberta draped over the 3-D Digital Elevation Model* .



Bouguer Gravity Map

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An anomaly indicates, indirectly and non-uniquely, some perturbation in the geometric distribution of a particular physical property of underlying rocks. These physical properties are affected by the rocks' entire history as well as present state. By itself, an anomaly says nothing about its rock-made source's nature, lithology or age. The rock property that relates gravity anomalies to rocks is density, and gravity anomalies represent lateral variations in the density of rocks.

The gravity field is unipolar, and almost perfectly vertical. Its measurable manifestation is acceleration due to gravity, measured commonly in Gals (1 Gal = 1cm/s^2 = 0.01 m/s^2) or milligals (1 mGal = 0.001 Gal). Bouguer gravity anomalies, used in this study as is commonly done in land areas, take account of the Earth's rotation, polar flattening, field station's elevation, and gravitational attraction of the rock mass lying above sea level. The gravity data for this study were supplied to the Alberta Geological Survey by the Geological Survey of Canada, in the Bouguer reduction, but (this being a relatively flat-topography region) without a terrain correction. Bouguer anomalies are generally considered to fairly represent the rock-density variations in the crust and asthenosphere.

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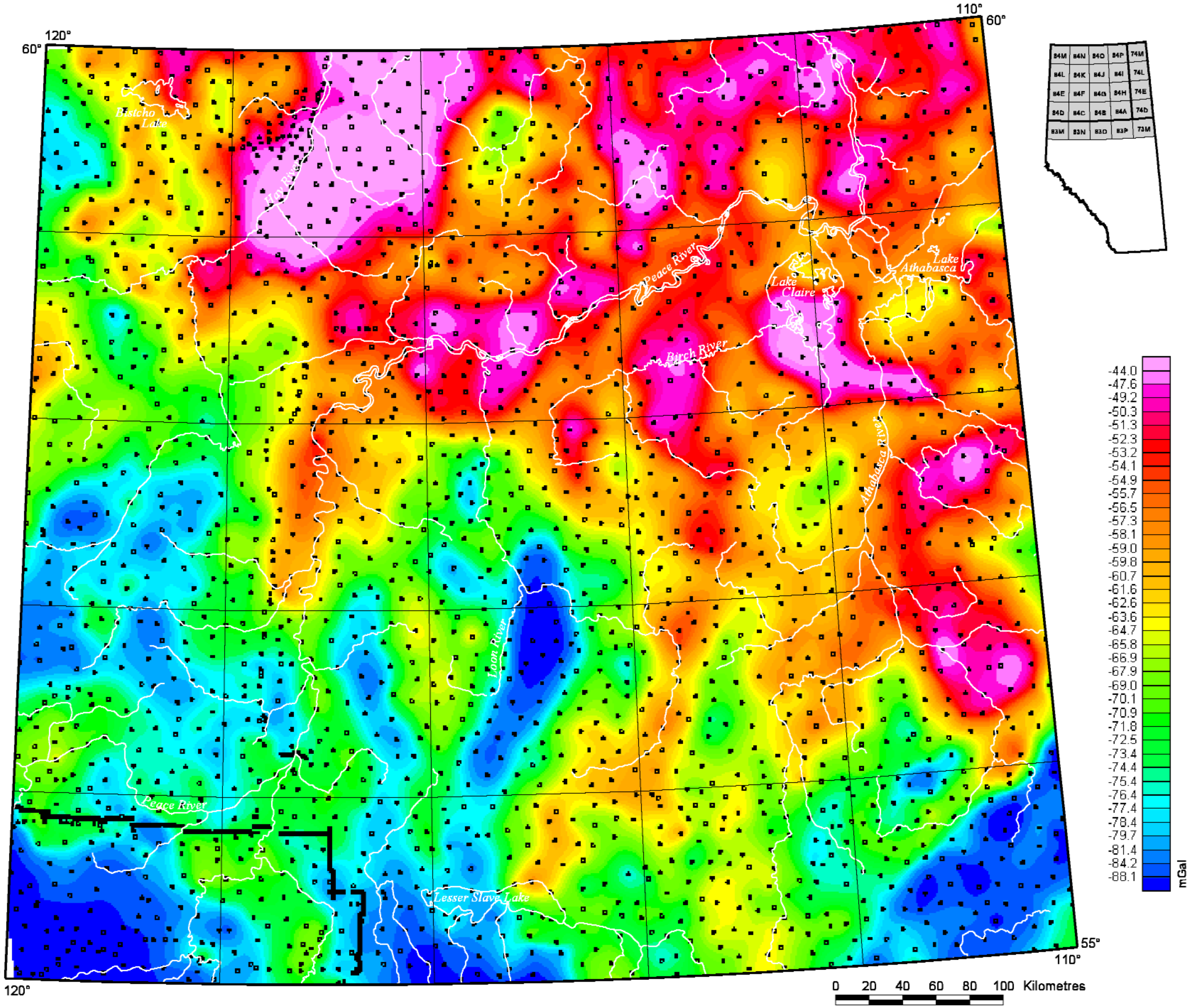
Map 2. Bouguer gravity map of northern Alberta (white lines indicate drainage).



Bouguer Gravity Map with Field Stations

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Due to difficulties of access in a region with comparatively little infrastructure, the gravity coverage in northern Alberta is usually sparser than the GSC standard of one field recording station per 10 km (roughly, one station per township). As a result, many small anomalies are missed or aliased, and the possibility of local gridding artifacts is increased. Despite this data shortcoming, careful processing has successfully revealed many subtle discontinuities in the gravity anomaly pattern, and these discontinuities' regional-scale length confirms their real sourcing in the rock mass.

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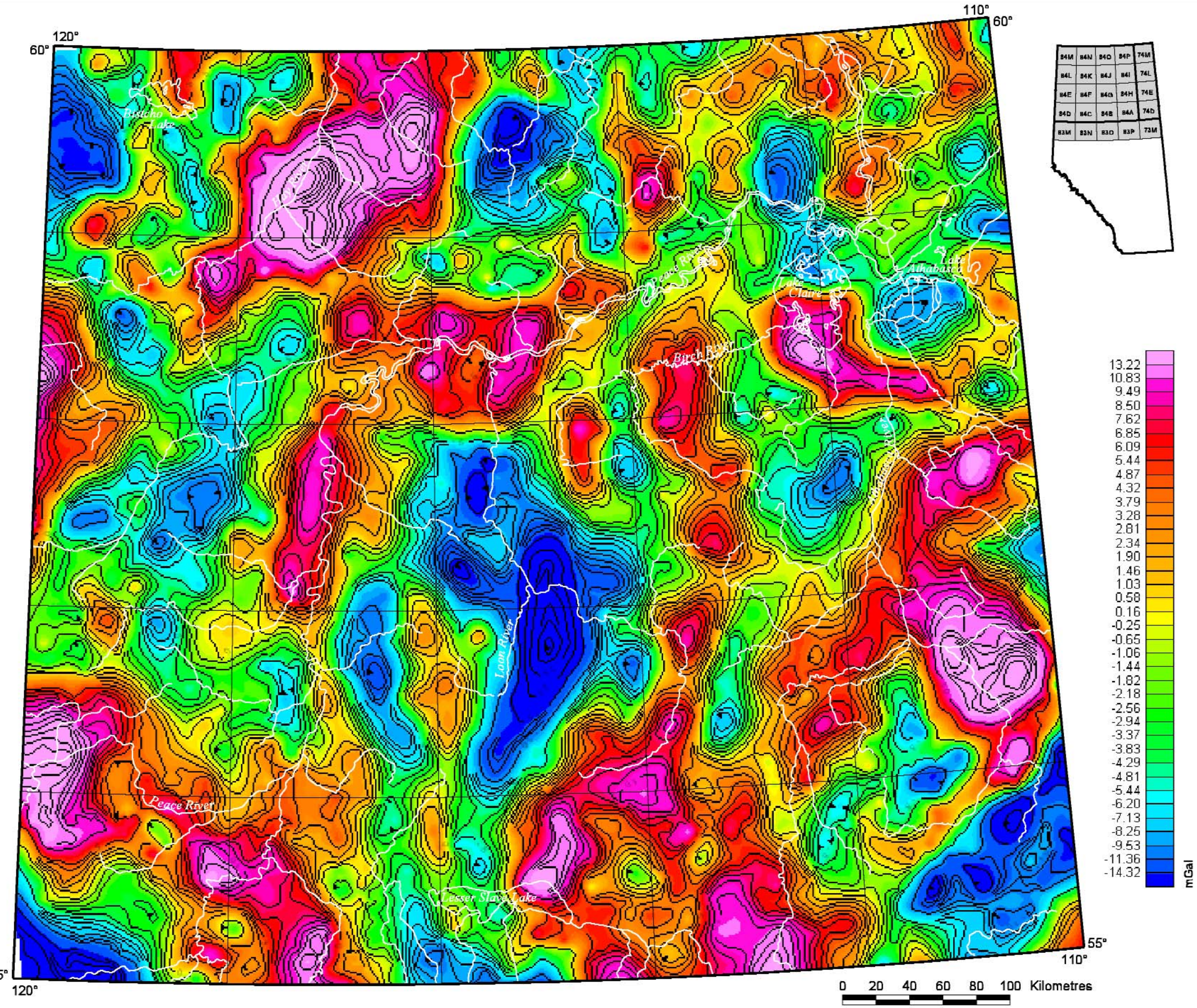
Map 3. Bouguer gravity map of northern Alberta with field stations.



Gravity Map with Regional Field Removed

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To highlight the local anomalies, the regional component of the anomaly field was subtracted from the data, generating a residual map. The definition of regional vs. local anomaly field is inevitably subjective and up to the user. Regional-anomaly separation can be achieved by bandpass wavelength filtering, but that procedure requires assuming the cut-off wavelengths, can smear the separation due to non-vertical filter roll-off, and can contaminate the data by Gibbs ringing. A more intuitive alternative is to compute from the gridded data the best fit smooth surface, of a selected low order, and then remove that smooth surface as the regional component.

A best fit surface of too low order may leave behind too much of the regional field. An order too high may cause the desirable local anomaly components to be removed. Good results in the western Canada Plains are often obtained by computing and subtracting from the data a third-order best fit surface, as was done to generate this map.

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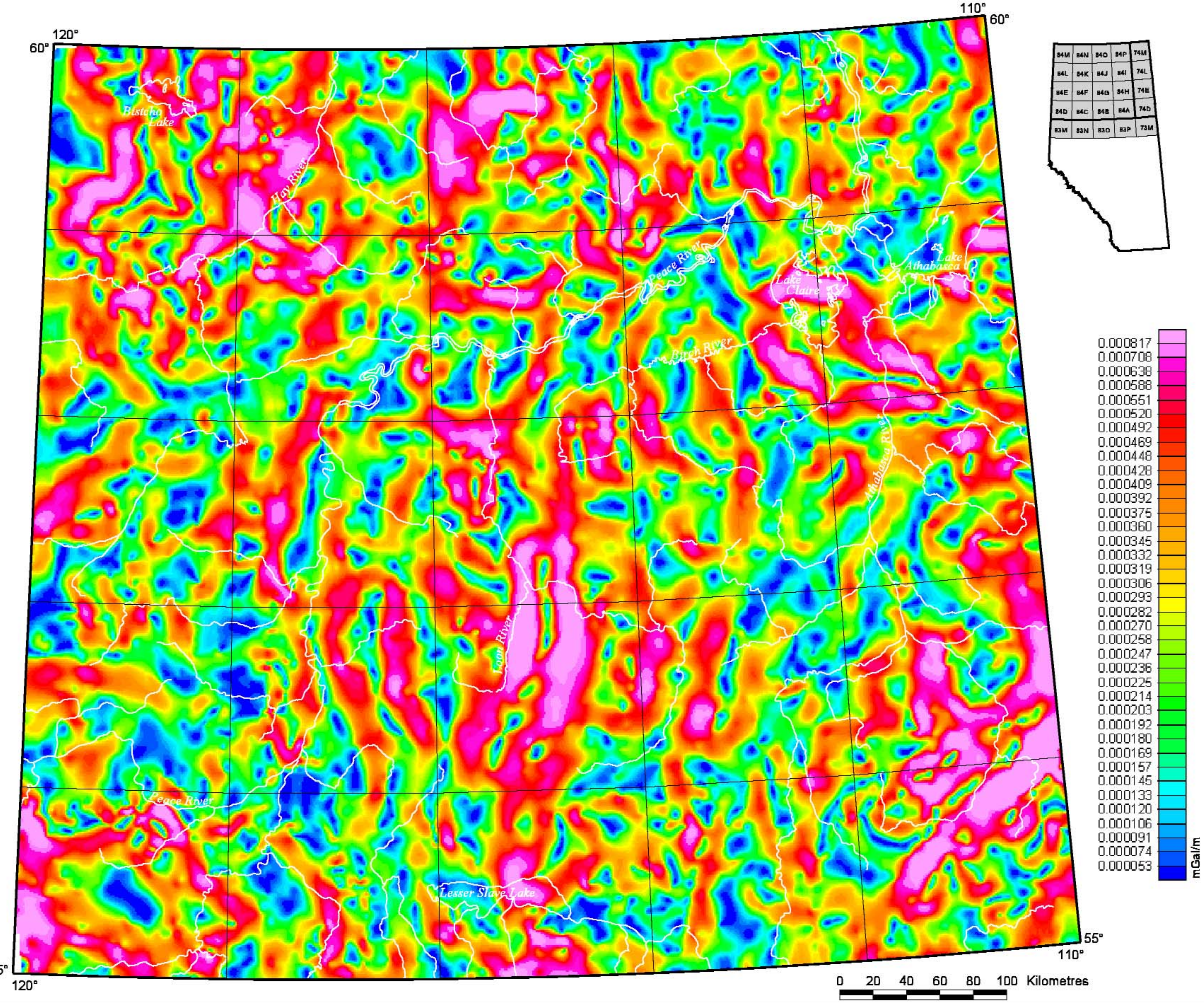
Map 4. Bouguer gravity map of northern Alberta with third-order trend removed.



Gravity Horizontal-Gradient Map

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To suppress short-wavelength noise, such as gridding artifacts around the sparse field stations, the gravity data were upward continued by one grid-cell size (1,000 m) prior to the creation of gradient maps.

Horizontal-gradient maps, along with shadowgrams, are among the most vivid and intuitive derivative products to reveal the anomaly texture of potential-field maps and to highlight discontinuities in the anomaly pattern. Horizontal-gradient maxima occur over the steepest parts of potential-field anomalies, and horizontal-gradient minima over the flattest parts. Short-wavelength anomalies are enhanced. More than vertical-gradient or analytic-signal maps, horizontal-gradient maps are very intuitive, as they can be easily related to the original potential-field anomalies.

The horizontal gradient is computed by (1) computing the partial derivatives of the mapped data set in two mutually orthogonal directions; (2) squaring the resulting values for each grid node; (3) adding the squares; and (4) taking the square root of the sum.

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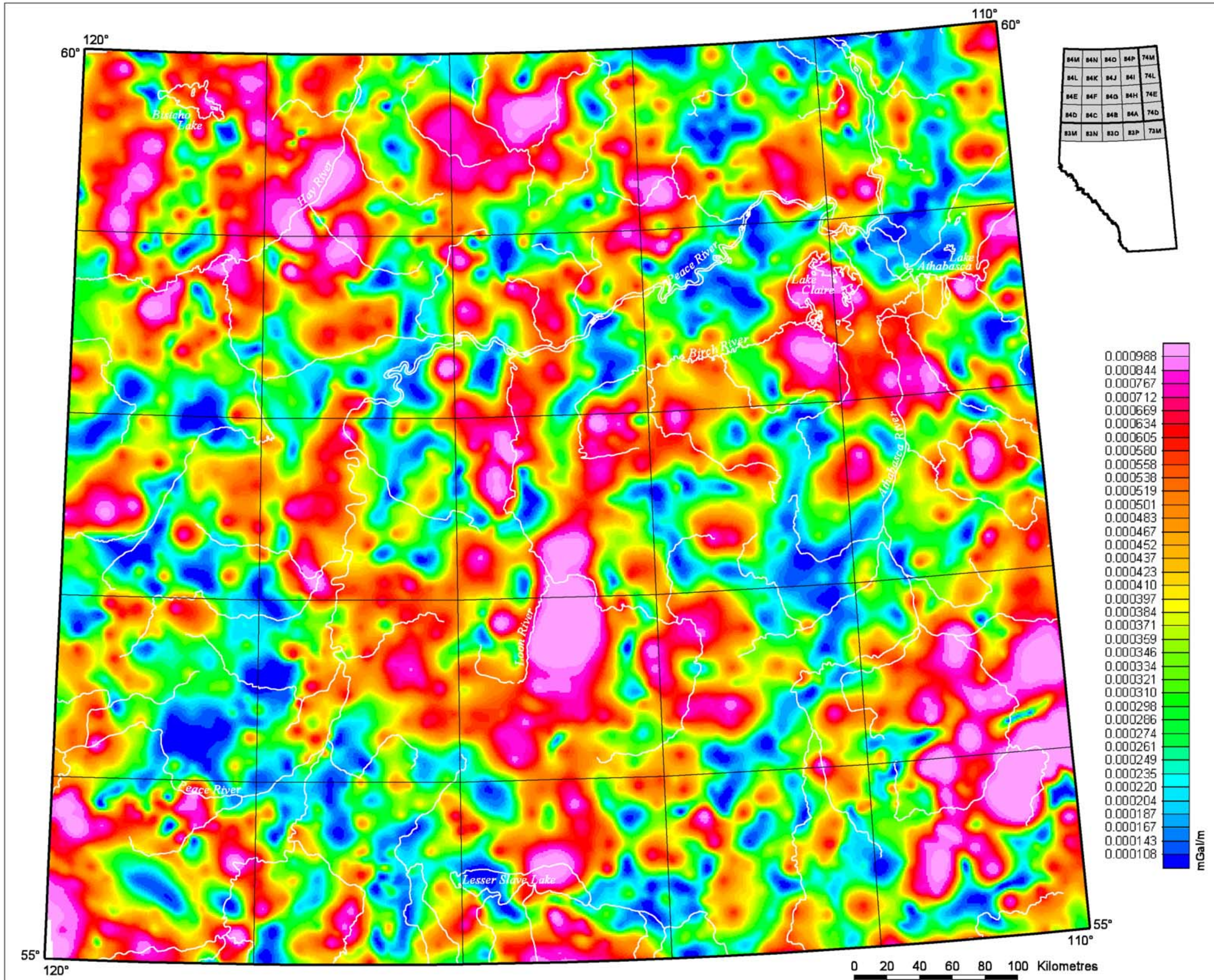
Map 5. Horizontal-gradient Bouguer gravity map of northern Alberta.



Gravity Analytic-Signal (Total-Gradient) Map

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To suppress short-wavelength noise, such as gridding artifacts around the sparse field stations, the gravity data were upward continued by two grid-cell size (2,000 m) prior to the creation of gradient maps.

Total-gradient (analytic-signal) maps help to reveal the anomaly texture of potential-field maps and to highlight discontinuities in the anomaly pattern. Short-wavelength anomalies are enhanced. Total-gradient maps are not entirely intuitive because they incorporate the vertical derivative, and they may be harder than horizontal-gradient maps to relate to the original anomaly shapes.

The total gradient is computed by (1) computing the partial horizontal derivatives of the mapped dataset in two mutually orthogonal directions; (2) computing the vertical gradient of the mapped dataset; (3) squaring the resulting partial-gradient values for each grid node; (4) adding the three squares; and (5) taking the square root of the sum.

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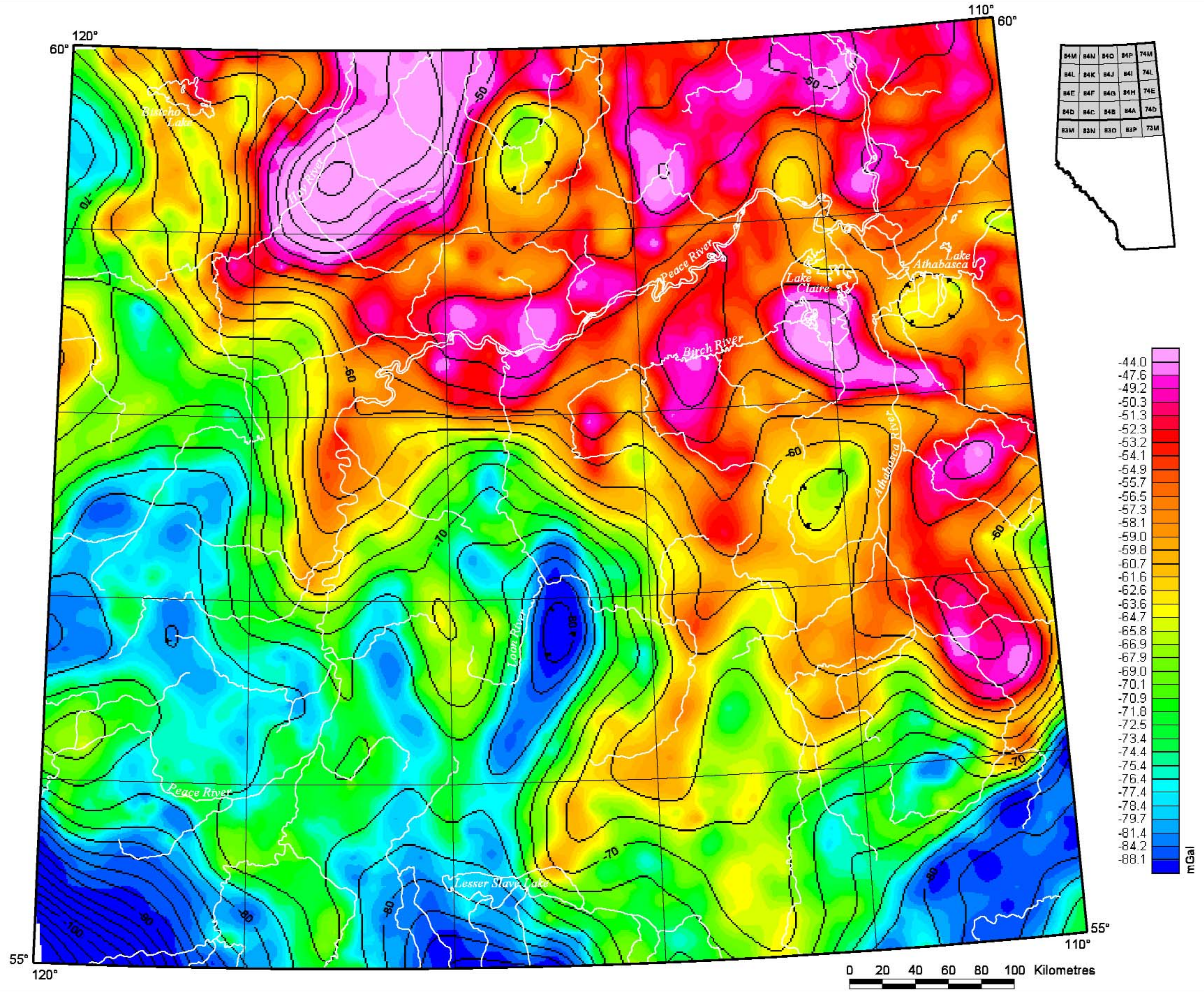
Map 6. Total-gradient (analytic-signal) Bouguer gravity map of northern Alberta.



Upward-Continued Gravity Map

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The large-scale regional anomaly pattern is revealed by upward continuation. This procedure uses wavelength filtering to simulate the appearance of potential-field maps if the data were recorded at a higher altitude than they actually were. For example, land data can be filtered to calculate what the same map would look like with the data flown at a user-specified high altitude. Short-wavelength anomalies are suppressed preferentially, where as anomalies with a significant long-wavelength component remain. The fundamental assumption that no anomaly sources exist between the real and simulated (nominal) recording levels holds reasonably well in the Canadian Plains, especially when the nominal recording level is taken to be very much higher than any topography.

Upward continuation is more intuitive than bandpass wavelength filtering, as it is easy to understand while avoiding the need for arbitrarily defined bandpass filters or the possibility of Gibbs ringing. The bulk structure of the upper crust is often revealed by upward continuing potential-field data to a nominal altitude of around 20 km. Because the gravity data in northern Alberta are sparsely recorded and, thus, have a diminished short-wavelength component to begin with, best results were obtained with upward continuation to only 15 km. The resultant maps show the largest anomalies, as well as the principal anomaly trends.

Comparing the upward-continued gravity data with the land data clearly shows which of the anomalies survive the filtering, and thus can be inferred to probably have massive rock sources. The anomalies that do not survive the upward continuation lack long-wavelength components and (by inference) large and massive sources.

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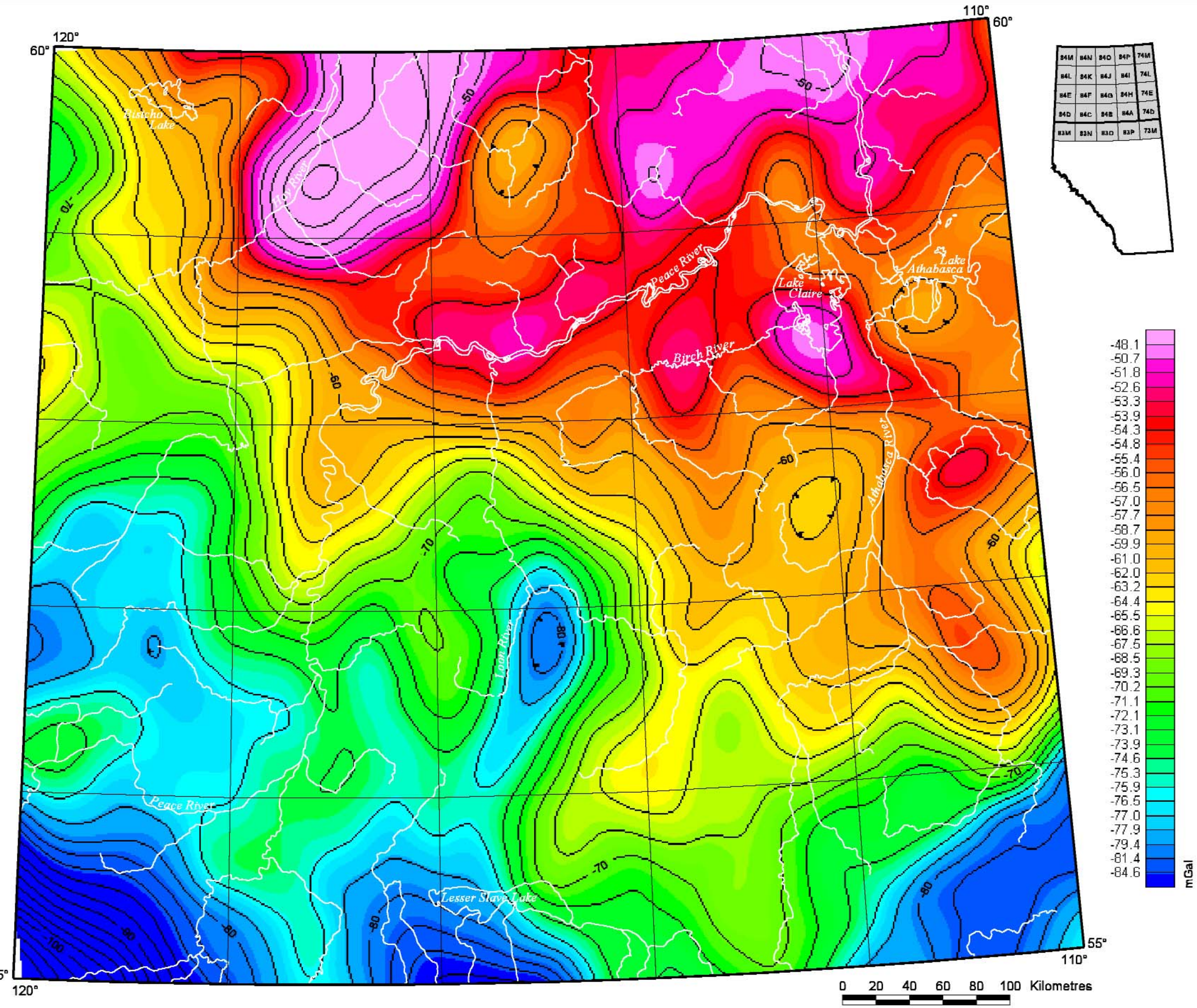
Map 7. Bouguer gravity map of northern Alberta (in colour) with superimposed contoured Bouguer gravity map upward continued to 15 km.



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Comparing the upward-continued gravity data with the land data clearly shows which of the anomalies survive the filtering, and thus can be inferred to probably have massive rock sources. The anomalies that do not survive the upward continuation lack long-wavelength components and (by inference) large and massive sources. Plotted on their own, upward-continued maps vividly reveal the principal anomaly shapes and trends.

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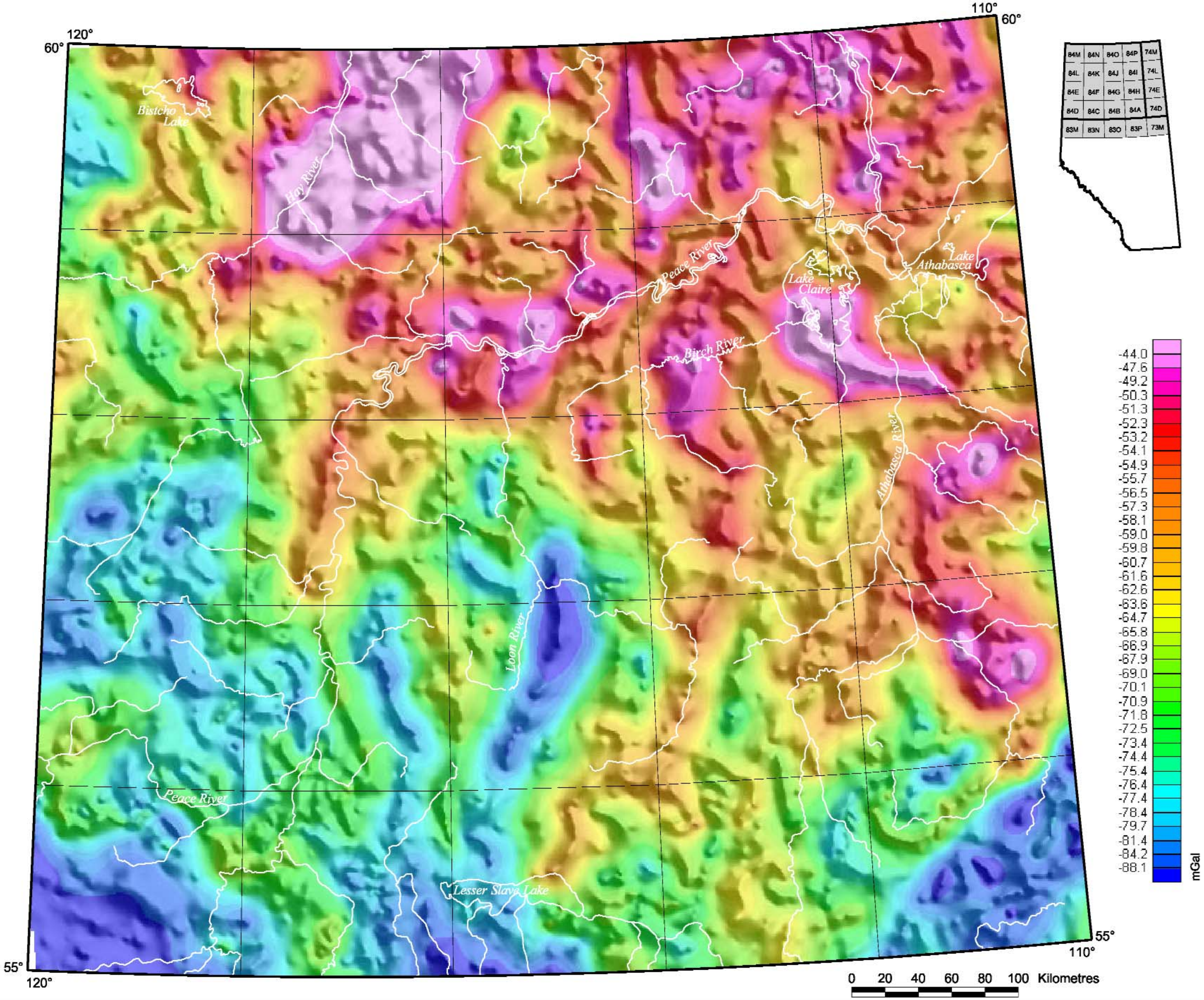
Map 8. Bouguer gravity map of northern Alberta upward continued to 15 km.



Gravity Vertical Shadowgram

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To suppress short-wavelength noise, such as gridding artifacts around the sparse field stations, the gravity data were upward continued by one grid-cell size (1000 m) prior to the creation of shadowgrams.

Shadowgrams, or shaded-relief maps, reveal variations in the dominant anomaly wavelengths and trends between regions. The computational procedure treats a potential-field map as a relief and computes the shadow pattern that would be created if this relief were illuminated by the sun from a user-specified angle.

The effect is analogous to taking aerial photographs of a terrain illuminated by the sun. Subtle, local and short-wavelength anomalies are emphasized, whereas broad and smooth features are made less visible. Sidelighting (illuminating from a non-vertical angle), however, acts as a directional filter, highlighting anomalies oriented at high angles to the 'sun' azimuth and suppressing anomalies parallel to the 'sun' azimuth. Such a directional bias is avoided in shadowgrams computed with a vertical sun angle, and the resulting vertical shadowgram simulates a horizontal-gradient map (steepest gradients are darkest). Vertical shadowgrams are vivid when plotted on their own or as layers on top of the colour-coded gravity maps.

Although vertical shadowgrams are comparable to horizontal-gradient maps overall, no 1:1 identity is to be expected between them. These two computational procedures are dissimilar in their nature and treatment of the data. The output data grids they produce may contain dissimilar local details and dynamic ranges, and they are plotted with different display parameters. With non-identical processing and display techniques, similar anomalies may thus be enhanced and highlighted differently. Beneficially for interpretation, vertical shadowgrams and horizontal-gradient maps are not redundant but complementary. In highlighting similar anomaly shapes and patterns, they reveal different information.

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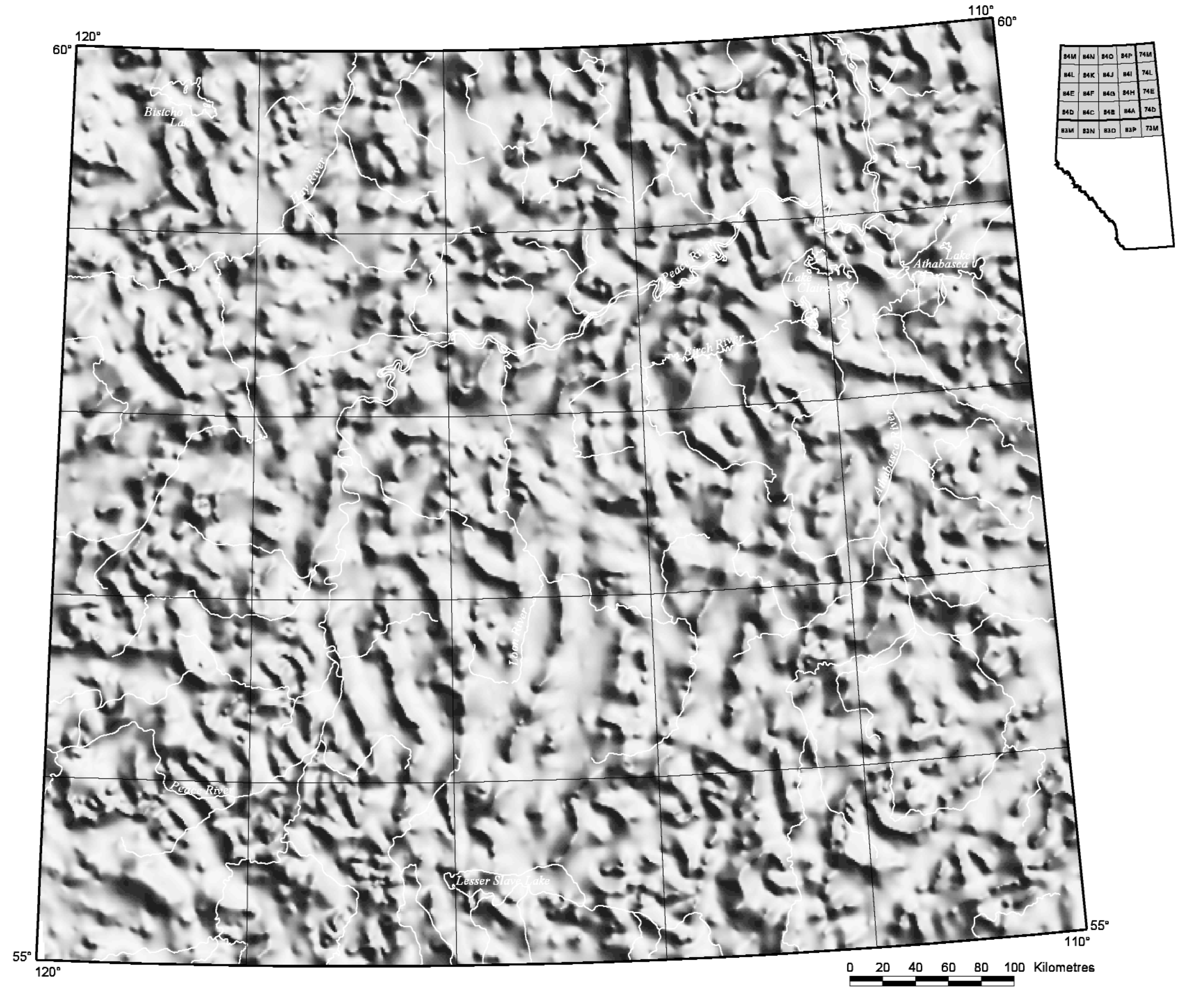
Map 9. Bouguer gravity map of northern Alberta with vertical-sun-angle shadowgram.



Map 10. Bouguer gravity vertical-sun-angle shadowgram of northern Alberta.

Gravity Vertical Shadowgram

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Shadowgrams, or shaded-relief maps, reveal variations in the dominant anomaly wavelengths and trends between regions. The computational procedure treats a potential-field map as a relief, and computes the shadow pattern that would be created if this relief were illuminated by the sun from a user-specified angle.

The effect is analogous to taking aerial photographs of a terrain illuminated by the sun. Subtle, local and short-wavelength anomalies are emphasized, whereas broad and smooth features are made less visible. Sidelighting (illuminating from a non-vertical angle), however, acts as a directional filter, highlighting anomalies oriented at high angles to the 'sun' azimuth and suppressing anomalies parallel to the 'sun' azimuth. Such a directional bias is avoided in shadowgrams computed with a vertical sun angle, and the resulting vertical shadowgram simulates a horizontal-gradient map (steepest gradients are darkest).

Although vertical shadowgrams are comparable to horizontal-gradient maps overall, no 1:1 identity is to be expected between them. These two computational procedures are dissimilar in their nature and treatment of the data. The output data grids they produce may contain dissimilar local details and dynamic ranges, and they are plotted with different display parameters. With non-identical processing and display techniques, similar anomalies may thus be enhanced and highlighted differently. Beneficially for interpretation, vertical shadowgrams and horizontal-gradient maps are not redundant but complementary. In highlighting similar anomaly shapes and patterns, they reveal different information.

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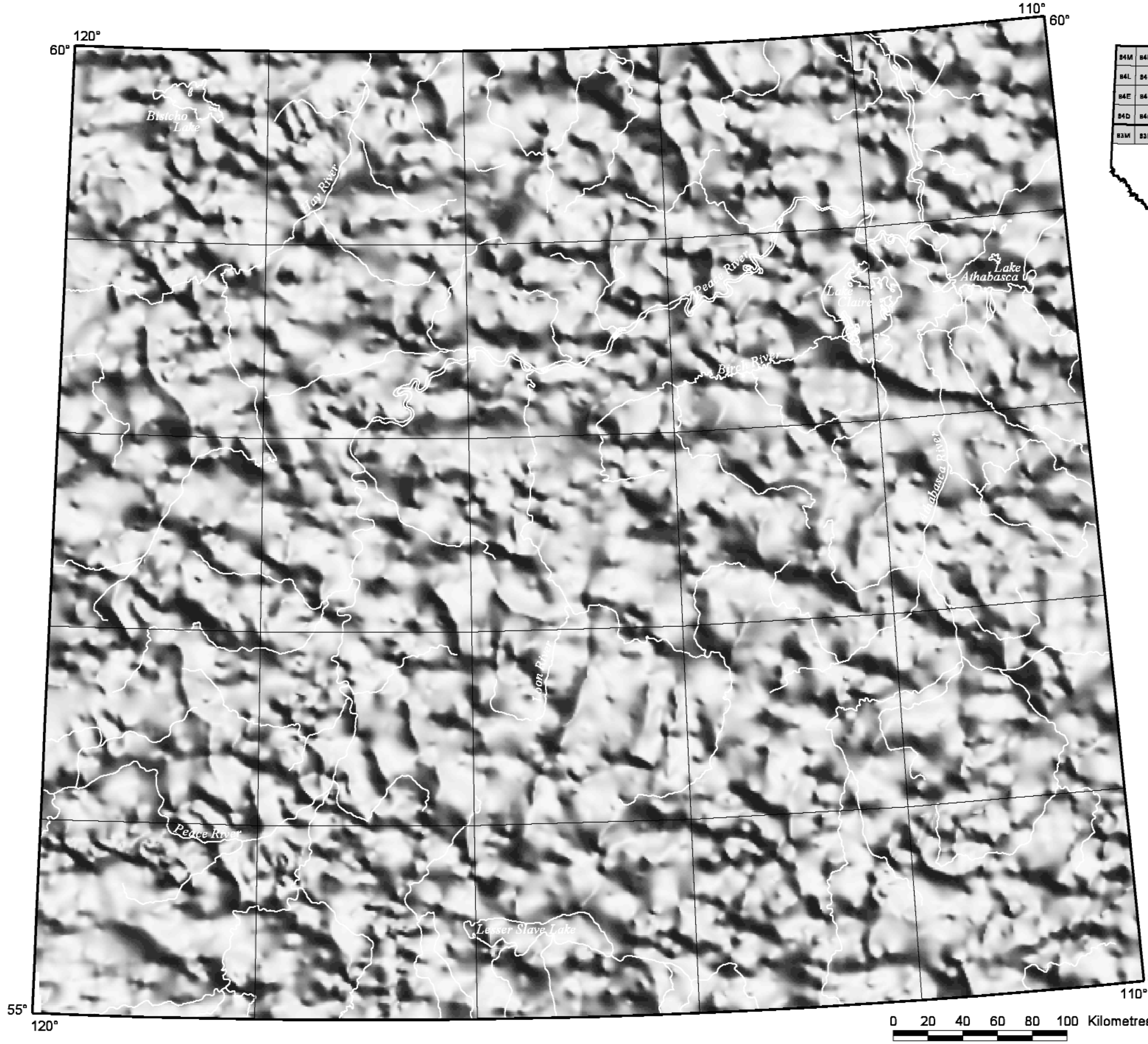

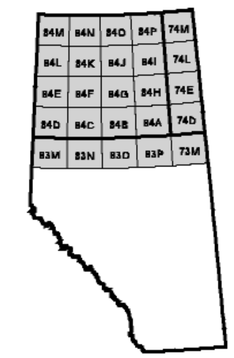

Gravity Shadowgrams

An anomaly is the difference between the observed or measured local value of a potential field and the same field's theoretical value predicted for the same location if the earth were more laterally uniform than it actually is. Geological sources of geophysical anomalies are variations in specific physical properties of rocks, within or between rock bodies.

An anomaly indicates, indirectly and non-uniquely, some perturbation in the geometric distribution of a particular physical property of underlying rocks. These physical properties are affected by the rocks' entire history as well as present state. By itself, an anomaly says nothing about its rock-made source's nature, lithology or age. The rock property that relates gravity anomalies to rocks is density, and gravity anomalies represent lateral variations in the density of rocks.

The gravity field is unipolar, and almost perfectly vertical. Its measurable manifestation is acceleration due to gravity, measured commonly in Gals (1 Gal = 1cm/s^2 = 0.01 m/s^2) or milligals (1 mGal = 0.001 Gal). Bouguer gravity anomalies, used in this study as is commonly done in land areas, take account of the Earth's rotation, polar flattening, field station's elevation, and gravitational attraction of the rock mass lying above sea level. The gravity data for this study were supplied to the Alberta Geological Survey by the Geological Survey of Canada in the Bouguer reduction, but (this being a relatively flat-topography region) without a terrain correction. Bouguer anomalies are generally considered to fairly represent the rock-density variations in the crust and asthenosphere.

Shadowgrams, or shaded-relief maps, reveal variations in the dominant anomaly wavelengths and trends between regions. The computational procedure treats a potential-field map as a relief, and computes the shadow pattern that would be created if this relief were illuminated by the sun from a user-specified angle.

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To suppress short-wavelength noise, such as gridding artifacts around the sparse field stations, the gravity data were upward continued by one grid-cell size (1,000 m) prior to the creation of shadowgrams. The optimal 'sun' inclination for this data set was found by experimentation to be 45° from the horizon. With that angle, a sweep of shadowgrams was generated, with 'sun' illumination from the north, northeast, east, southeast, south, southwest, west and northwest.

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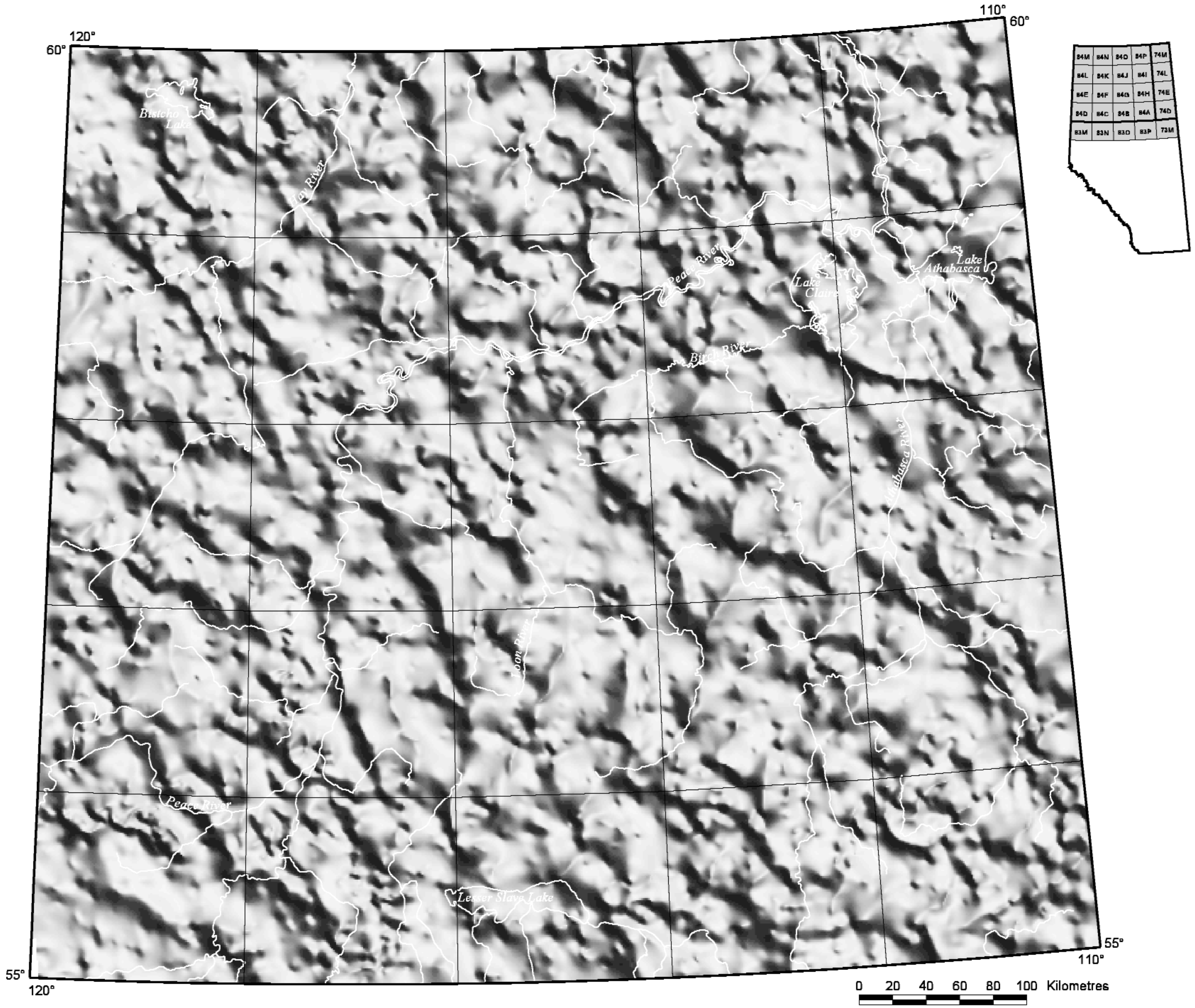
Map 11. Bouguer gravity shadowgram of northern Alberta illuminated from the north.



Gravity Shadowgrams

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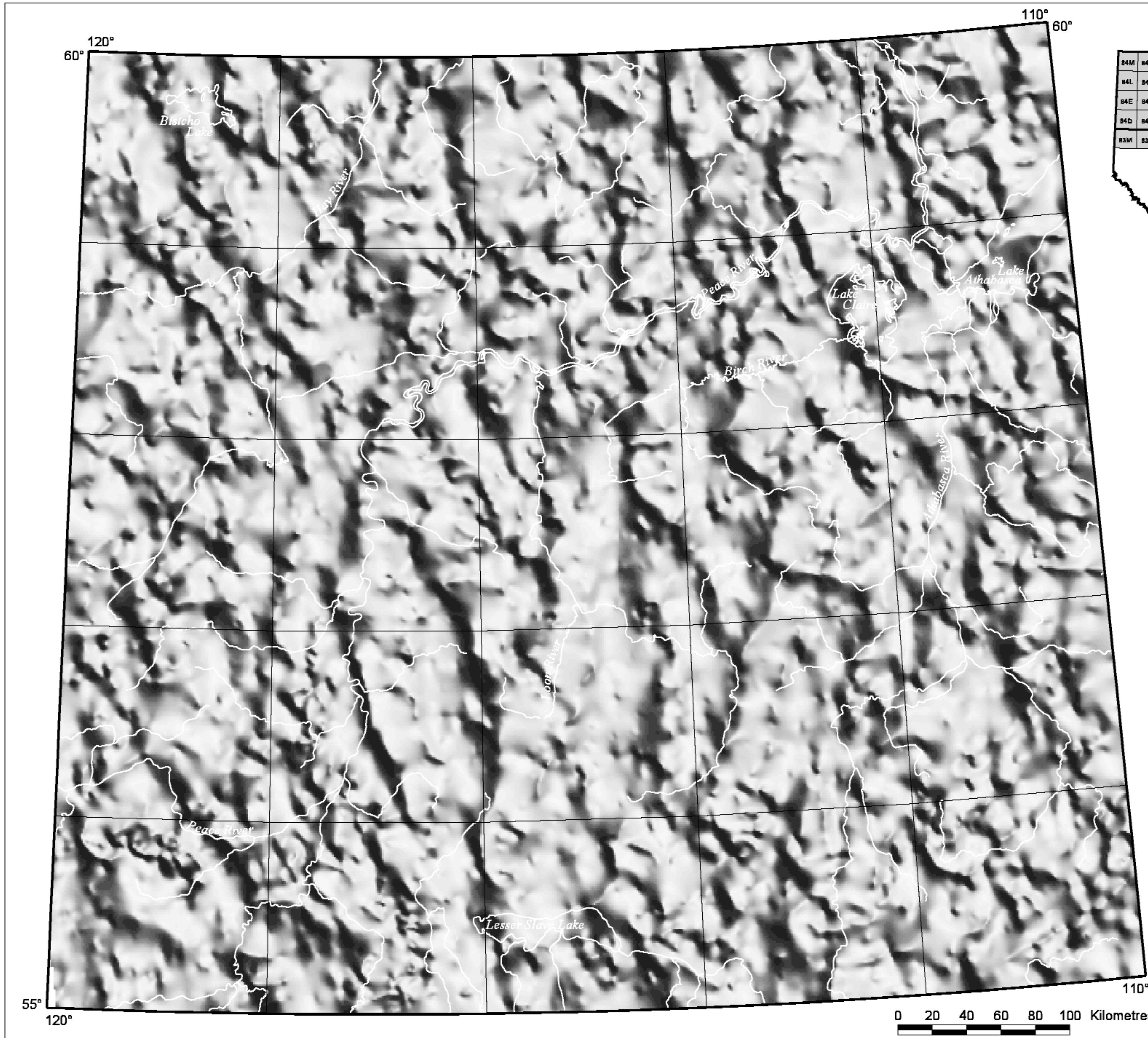
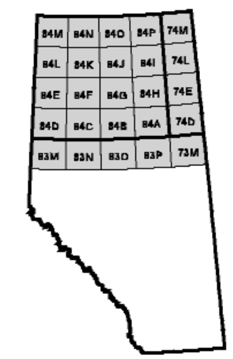
Map 12. Bouguer gravity shadowgram of northern Alberta illuminated from the northeast.





Gravity Shadowgrams

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To suppress short-wavelength noise, such as gridding artifacts around the sparse field stations, the gravity data were upward continued by one grid-cell size (1,000 m) prior to the creation of shadowgrams. The optimal 'sun' inclination for this dataset was found by experimentation to be 45° from the horizon. With that angle, a sweep of shadowgrams was generated, with 'sun' illumination from the north, northeast, east, southeast, south, southwest, west and northwest.

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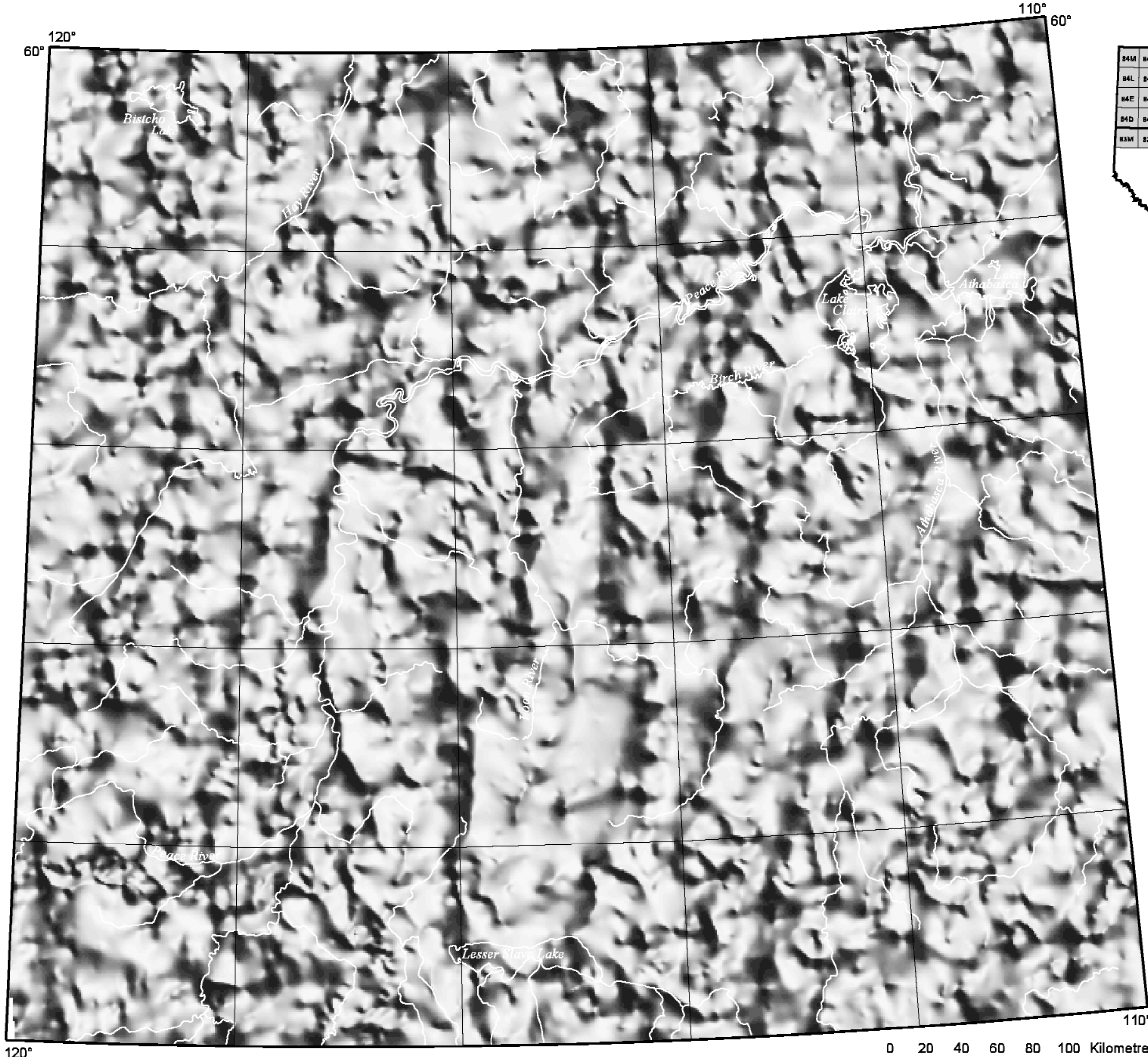
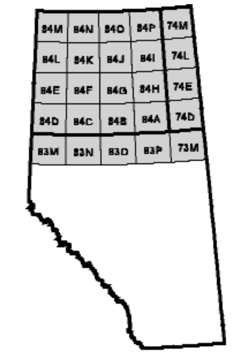
Map 13. Bouguer gravity shadowgram of northern Alberta illuminated from the east.





Gravity Shadowgrams

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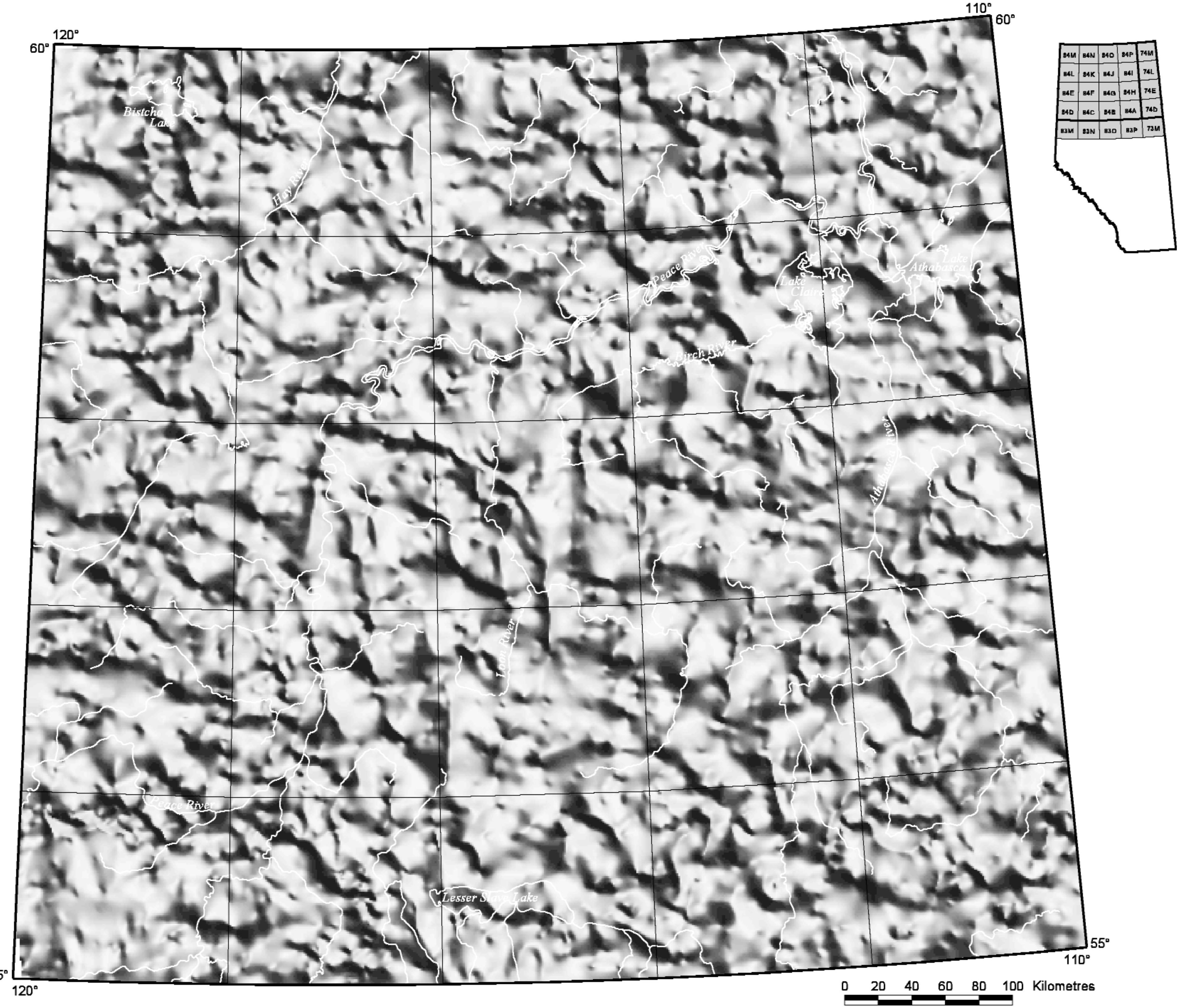
Map 14. Bouguer gravity shadowgram of northern Alberta illuminated from the southeast.



Gravity Shadowgrams

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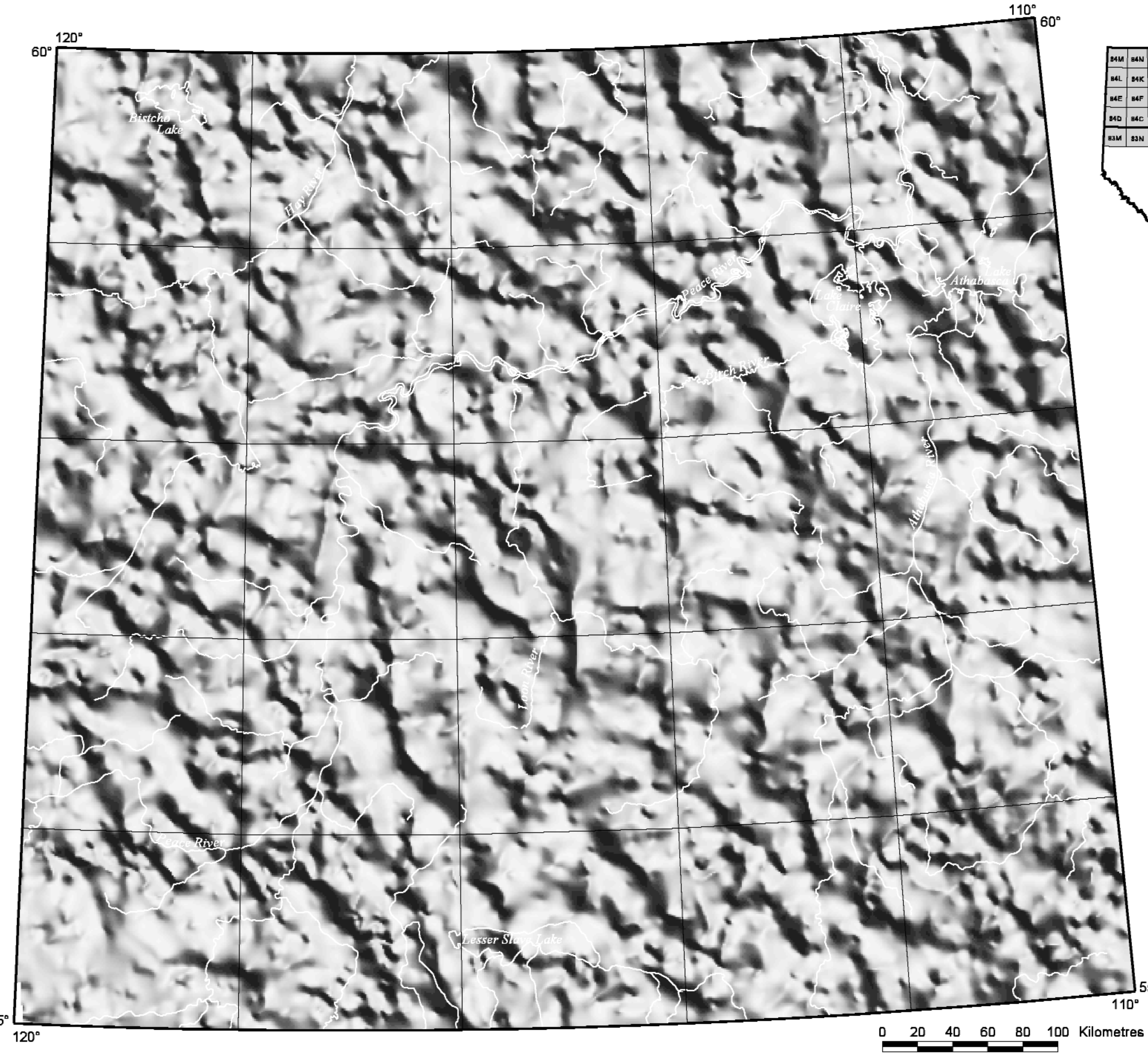
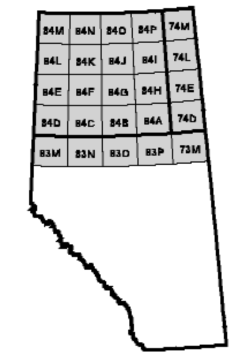
Map 15. Bouguer gravity shadowgram of northern Alberta illuminated from the south.





Gravity Shadowgrams

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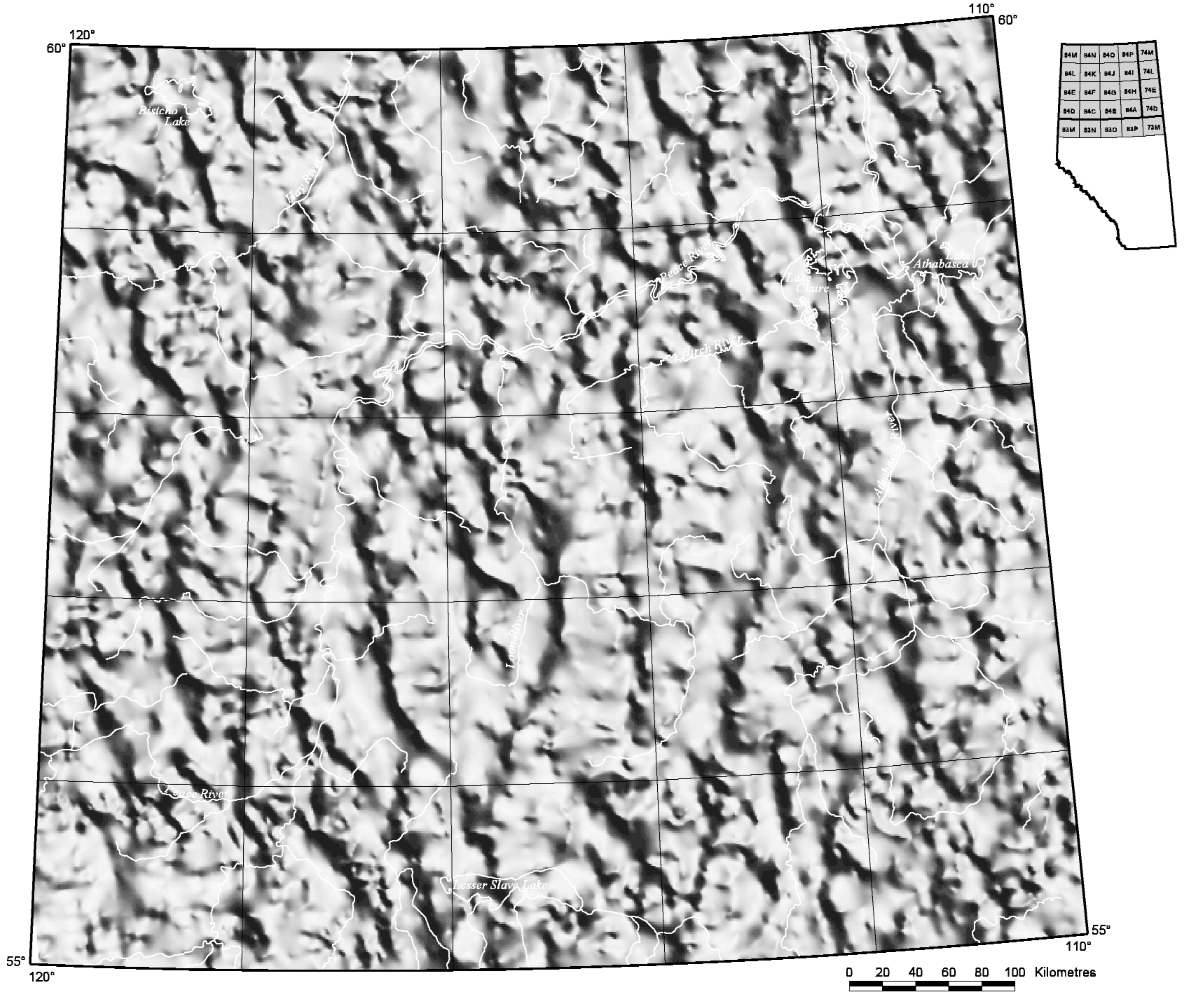
Map 16. Bouguer gravity shadowgram of northern Alberta illuminated from the southwest.



Gravity Shadowgrams

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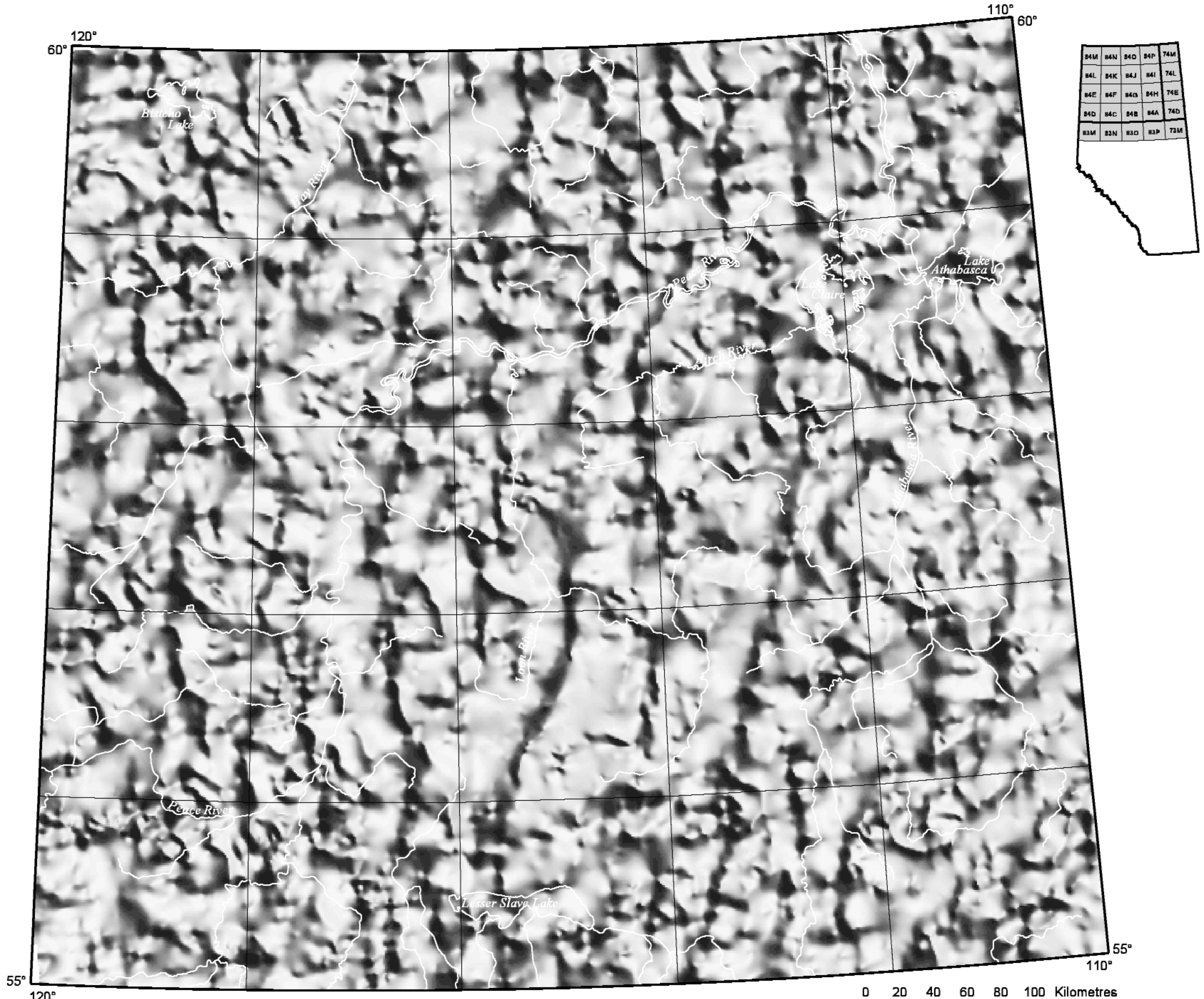
Map 17. Bouguer gravity shadowgram of northern Alberta illuminated from the west.



Gravity Shadowgrams

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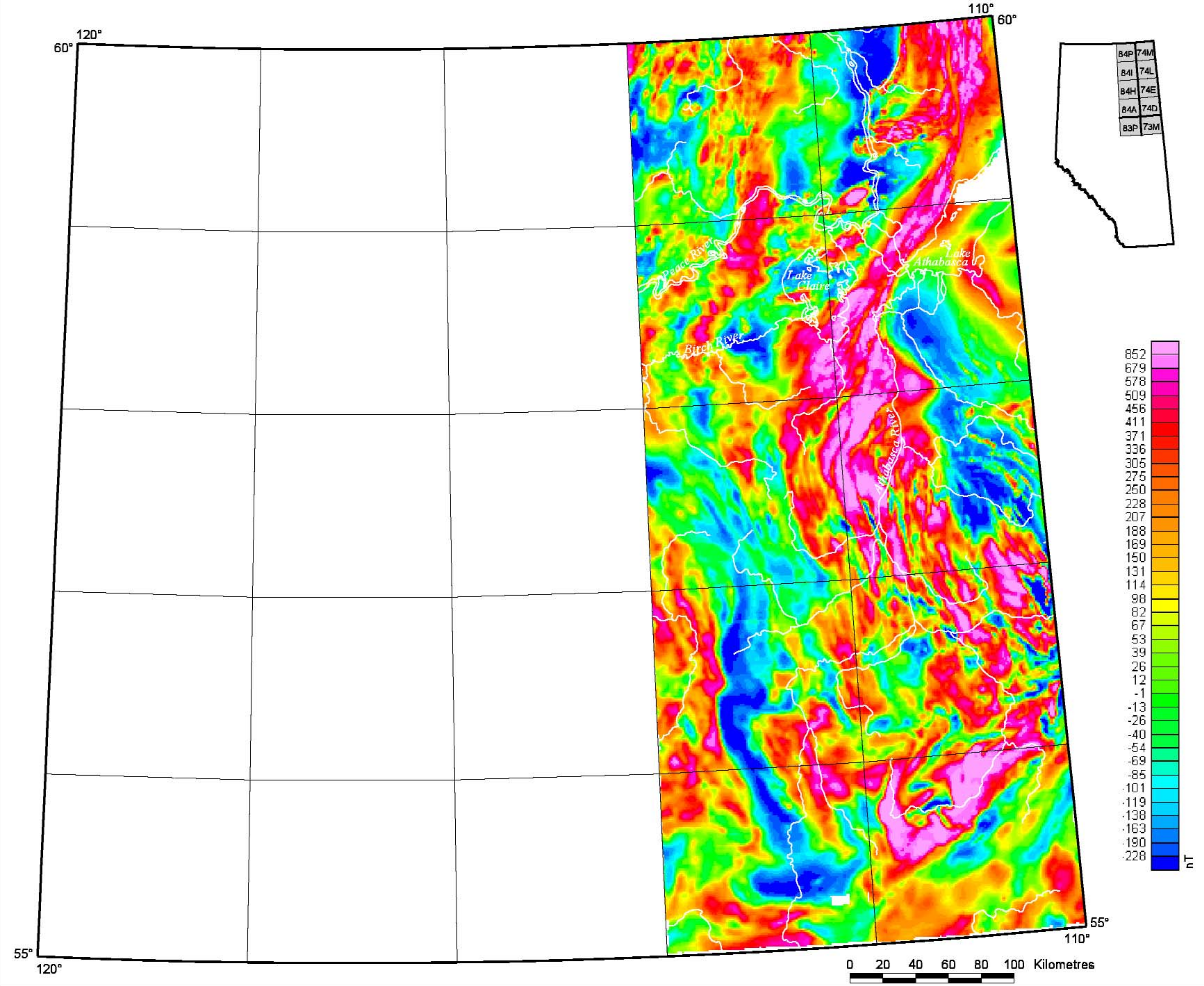
Map 18. Bouguer gravity shadowgram of northern Alberta illuminated from the northwest.



Total-Field Magnetic Map

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The rock property that relates magnetic anomalies to rocks is total magnetization, and magnetic anomalies represent lateral variations in the total magnetization of rocks. Total rock magnetization is normally complex and composite. It may consist of multiple, ill-understood remanent magnetizations of various types and vintages, as well as magnetization induced by the ambient geomagnetic field.

Rock magnetization is often carried by certain minerals whose distribution may have little relation to the bulk lithological and structural patterns in the rock mass. Rocks lose their ability to support magnetization when heated above the Curie temperature (575° C for magnetite). In cratonic regions, the Curie isotherm is commonly thought to lie in the lower crust or uppermost mantle (depending on the geothermal gradient), and rocks deeper than this isotherm are not represented in the magnetic anomalies.

The magnetic field itself is complex: dipolar, non-vertical. The standard unit of magnetic measurements used in exploration geophysics is nanoTesla (nT). The magnetic data for this study were supplied to the Alberta Geological Survey by the Geological Survey of Canada, with the International Geomagnetic Reference Field reduction that subtracts from the recorded magnetic values the theoretical values computed for an assumed laterally uniform Earth.

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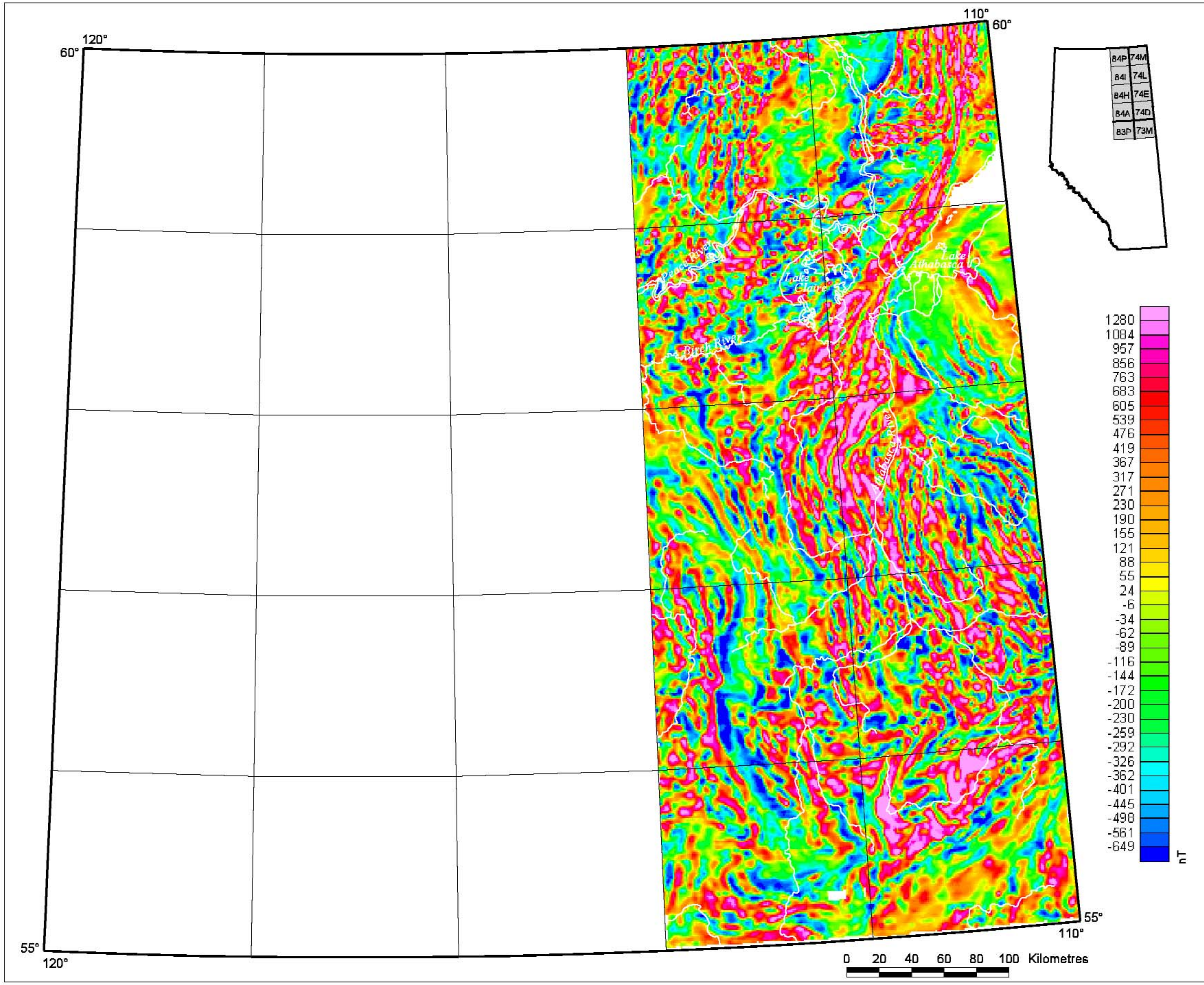
Map 19. Total-field magnetic map of northeastern Alberta.



Magnetic Map with Amplitude Gain

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To highlight the details of local magnetic anomalies, an automatic gain-control (AGC) procedure comparatively boosts anomaly amplitudes in areas with smooth anomalies. Without sacrificing the long-wavelength information, such enhancement of the local anomaly 'relief' usefully sharpens the appearance and definition of subtle breaks in the anomaly pattern.
Gain is estimated by using a sliding filter window, centred on each grid node in turn. Local AGC calculation with a window of 25 grid nodes on the side was found to produce the best results for these data (with the 400 m grid spacing, the filter window was 9600 m). The maximum gain correction (10, in this case) is specified to prevent the procedure from blowing up in the areas of low signal. Anomalies with the dominant wavelength exceeding the window size are comparatively little affected by the AGC calculation, whereas anomalies equal to or smaller than the window are affected strongly.
Inside the filter window, centred at each position, the best-fitting plane is calculated, which minimizes the root-mean-square misfit with the data.
The average RMS difference between the data and plane values within the window represents the local signal gain. Signal at the grid node in the centre of the window is the difference between the data value and the plane value at that position. The first pass over the grid determines the signal and gain for each position and records the largest (maximum) gain encountered. In the second pass, the signal at each position is multiplied by the ratio of maximum to local gain, not exceeding the maximum correction of 10. The new, gained signal is then added to the original background value to obtain the final signal value.

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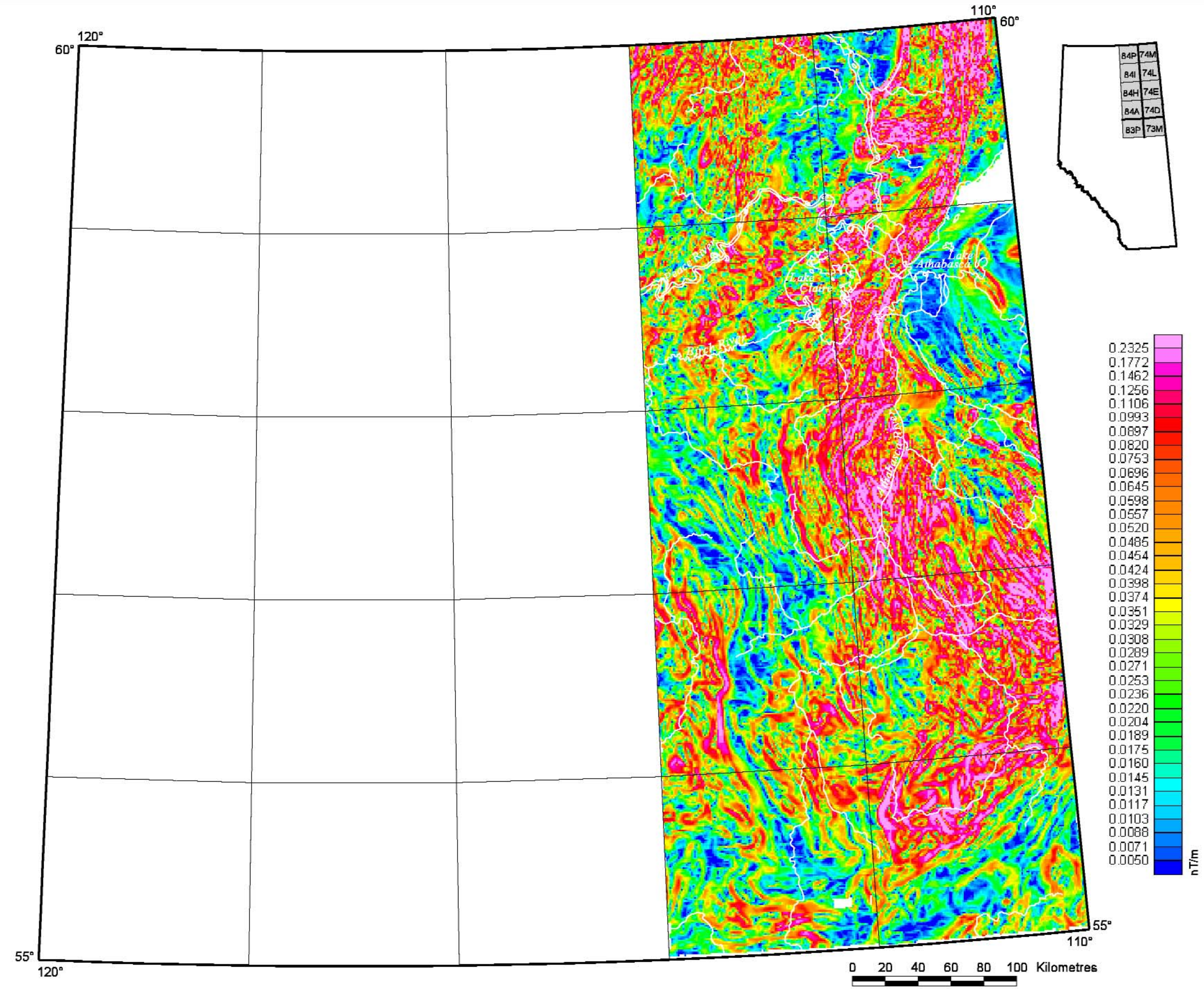
Map 20. Total-field magnetic map of northeastern Alberta with local amplitude gain control.



Magnetic Horizontal-Gradient Map

An anomaly is the difference between the observed or measured local value of a potential field and the same field's theoretical value predicted for the same location if the Earth were more laterally uniform than it actually is. Geological sources of geophysical anomalies are variations in specific physical properties of rocks, within or between rock bodies.

An anomaly indicates, indirectly and non-uniquely, some perturbation in the geometric distribution of a particular physical property of underlying rocks. These physical properties are affected by the rocks' entire history as well as present state. By itself, an anomaly says nothing about its rock-made source's nature, lithology or age.

The rock property that relates magnetic anomalies to rocks is total magnetization, and magnetic anomalies represent lateral variations in the total magnetization of rocks. Total rock magnetization is normally complex and composite. It may consist of multiple, ill-understood remanent magnetizations of various types and vintages, as well as magnetization induced by the ambient geomagnetic field.

Rock magnetization is often carried by certain minerals whose distribution may have little relation to the bulk lithological and structural patterns in the rock mass. Rocks lose their ability to support magnetization when heated above the Curie temperature (575°C for magnetite). In cratonic regions, the Curie isotherm is commonly thought to lie in the lower crust or uppermost mantle (depending on the geothermal gradient), and rocks deeper than this isotherm are not represented in the magnetic anomalies.

The magnetic field itself is complex: dipolar, non-vertical. The standard unit of magnetic measurements used in exploration geophysics is nanoTesla (nT). The magnetic data for this study were supplied to the Alberta Geological Survey by the Geological Survey of Canada, with the International Geomagnetic Reference Field reduction that subtracts from the recorded magnetic values the theoretical values computed for an assumed laterally uniform Earth.

To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of gradient maps.

No pole reduction of the magnetic data was undertaken, prior to the gradient computation, for two reasons: (1) northern Alberta lies at a high magnetic latitude, so changes to the data would be small; and (2) reduction to pole assumes all rock magnetization to be induced and remanence-free, but studies in the Canadian Shield in northeastern Alberta show these crystalline rocks to carry both induced and remanent magnetization.

Horizontal-gradient maps, along with shadowgrams, are among the most vivid and intuitive derivative products to reveal the anomaly texture of potential-field maps and highlight discontinuities in the anomaly pattern. Horizontal-gradient maxima occur over the steepest parts of potential-field anomalies and horizontal-gradient minima over the flattest parts. Short-wavelength anomalies are enhanced. More than vertical-gradient or analytic-signal maps, horizontal-gradient maps are very intuitive, as they can be easily related to the original potential-field anomalies.

The horizontal gradient is computed by (1) computing the partial derivatives of the mapped dataset in two mutually orthogonal directions; (2) squaring the resulting values for each grid node; (3) adding the squares; and (4) taking the square root of the sum.

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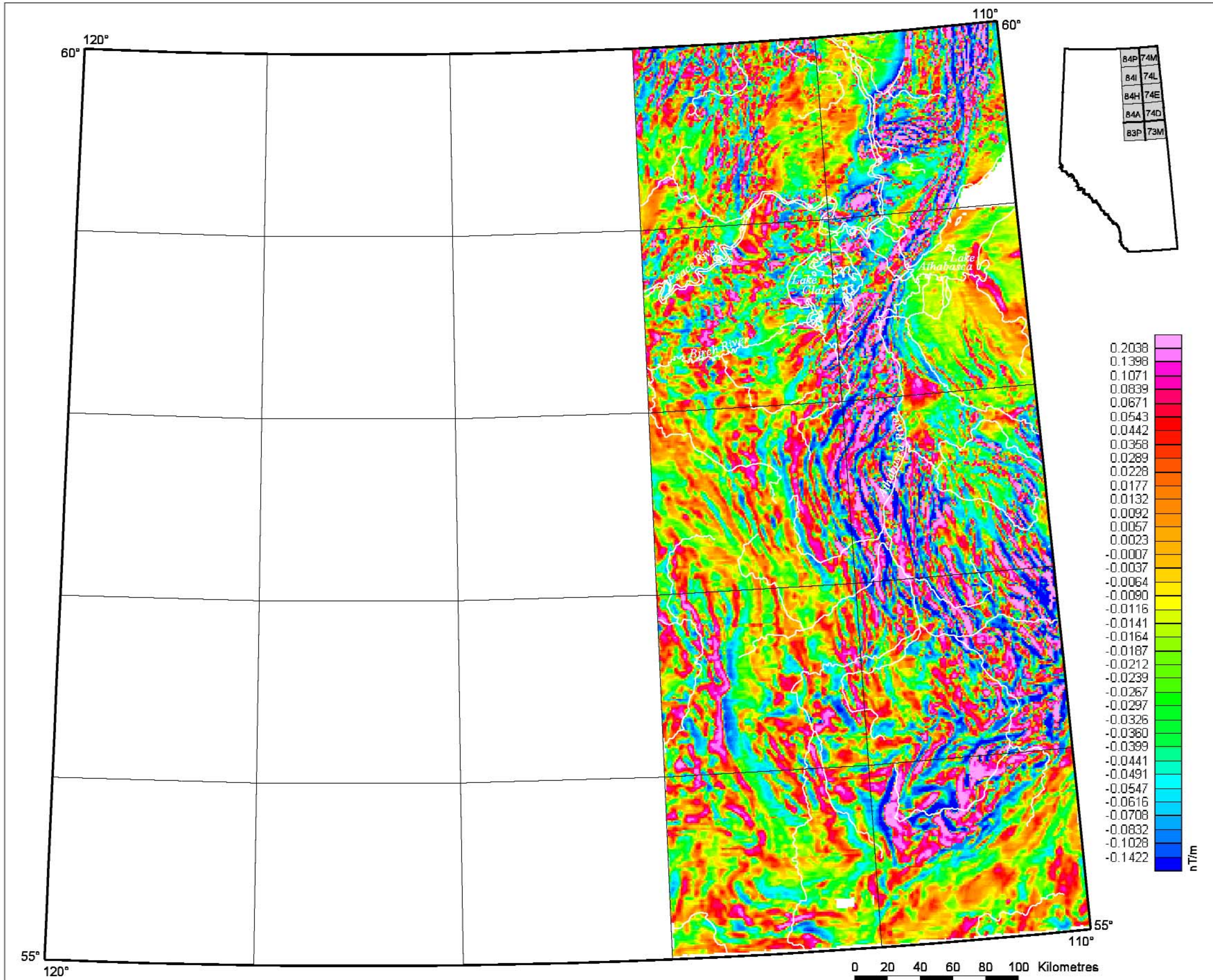
Map 21. Horizontal-gradient magnetic map of northeastern Alberta.



Magnetic Vertical-Gradient Map

An anomaly is the difference between the observed or measured local value of a potential field and the same field's theoretical value predicted for the same location if the Earth were more laterally uniform than it actually is. Geological sources of geophysical anomalies are variations in specific physical properties of rocks, within or between rock bodies.

An anomaly indicates, indirectly and non-uniquely, some perturbation in the geometric distribution of a particular physical property of underlying rocks. These physical properties are affected by the rocks' entire history as well as present state. By itself an anomaly says nothing about its rock-made source's nature, lithology or age.

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To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of gradient maps.

Vertical-derivative (vertical-gradient) maps accentuate short-wavelength components of the anomaly field, while de-emphasizing long-wavelength components. The vertical gradient can be thought of as the rate of change of anomaly values as the potential-field data are upward continued. Such maps are not intuitive, and they may be harder than horizontal-gradient maps to relate to the original anomaly shapes. Nonetheless, vertical-gradient maps are useful tools for highlighting the details of anomaly texture, as well as the discontinuities and breaks in the anomaly pattern.

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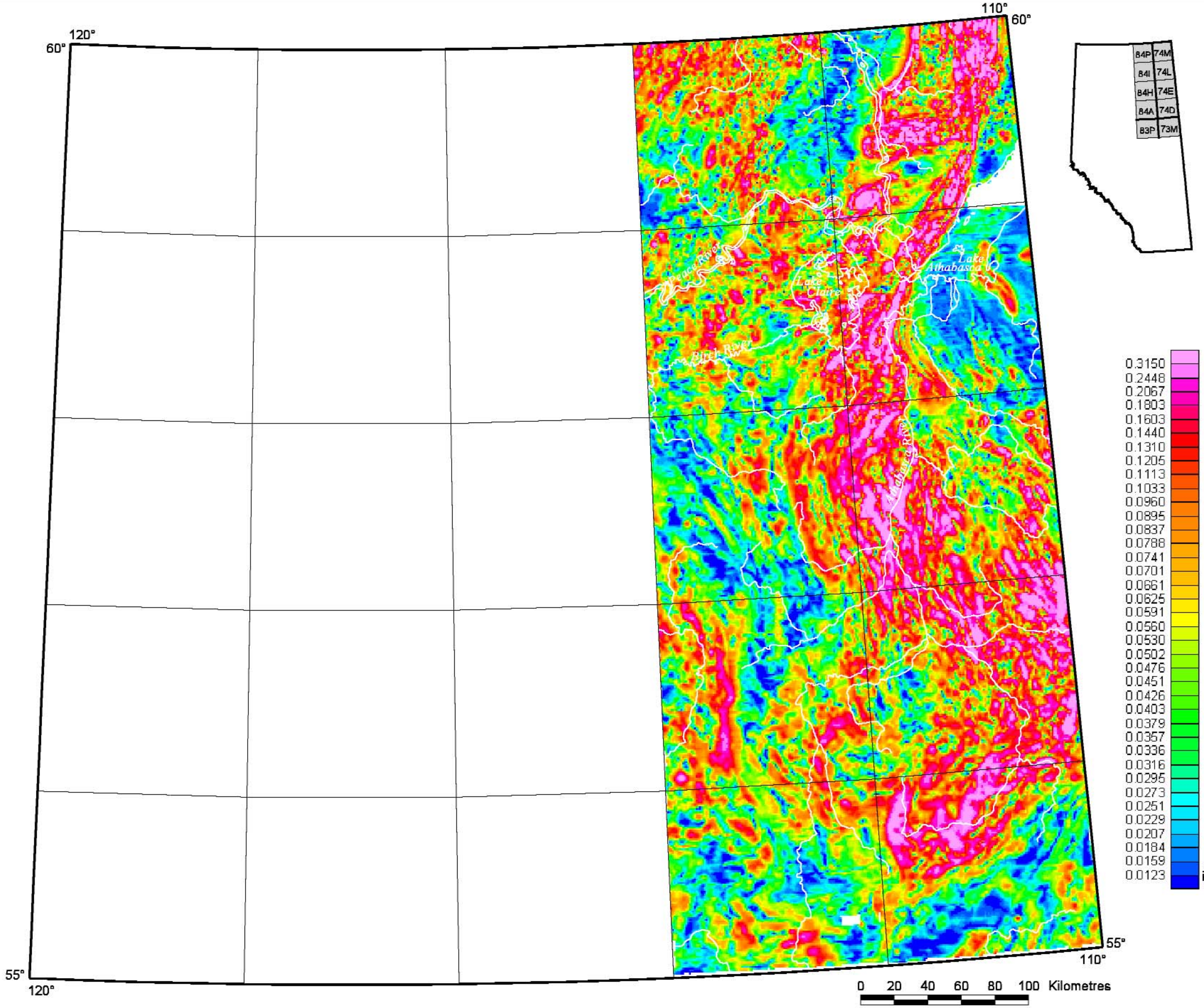
Map 22. Vertical-gradient magnetic map of northeastern Alberta.



Magnetic Analytic-Signal (Total-Gradient) Map

An anomaly is the difference between the observed or measured local value of a potential field and the same field's theoretical value predicted for the same location if the Earth were more laterally uniform than it actually is. Geological sources of geophysical anomalies are variations in specific physical properties of rocks, within or between rock bodies.

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To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of gradient maps.

No pole reduction of the magnetic data was undertaken prior to the gradient computation, for two reasons: (1) northern Alberta lies at a high magnetic latitude, so changes to the data would be small; and (2) reduction to pole assumes all rock magnetization to be induced and remanence-free, but studies in the Canadian Shield in northeastern Alberta show these crystalline rocks to carry both induced and remanent magnetization.

Total-gradient (analytic-signal) maps help to reveal the anomaly texture of potential-field maps and highlight discontinuities in the anomaly pattern. Short-wavelength anomalies are enhanced. Total-gradient maps are not entirely intuitive because they incorporate the vertical derivative, and they may be harder than horizontal-gradient maps to relate to the original anomaly shapes.

The total gradient is computed by (1) computing the partial horizontal derivatives of the mapped dataset in two mutually orthogonal directions; (2) computing the vertical gradient of the mapped dataset; (3) squaring the resulting partial-gradient values for each grid node; (4) adding the three squares; and (5) taking the square root of the sum.

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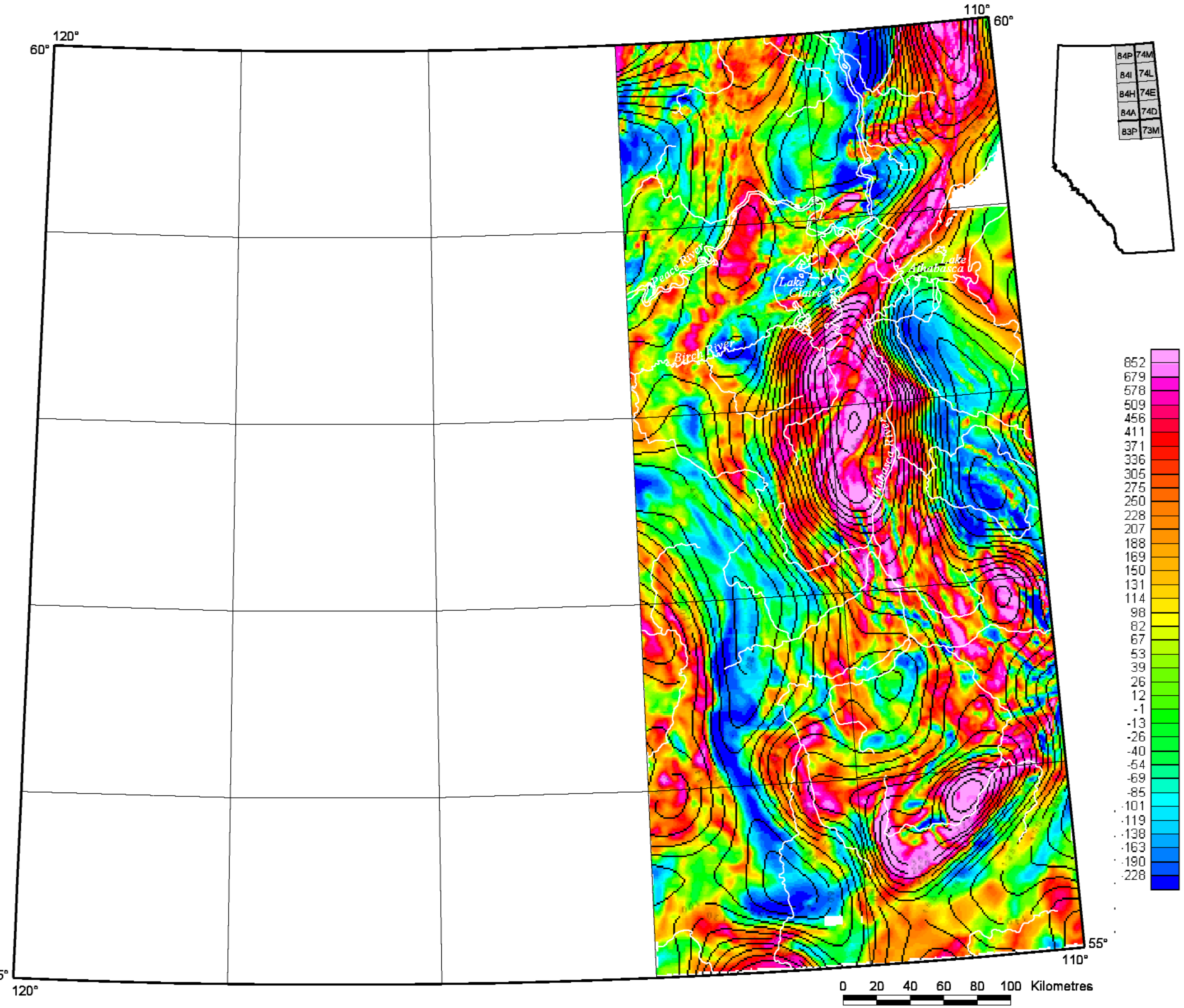
Map 23. Total-gradient (analytic-signal) magnetic map of northeastern Alberta.



Upward Continued Magnetic Map

An anomaly is the difference between the observed or measured local value of a potential field and the same field's theoretical value predicted for the same location if the earth were more laterally uniform than it actually is. Geological sources of geophysical anomalies are variations in specific physical properties of rocks, within or between rock bodies.

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The large-scale regional anomaly pattern is revealed by upward continuation. This procedure uses wavelength filtering to simulate the appearance of potential-field maps if the data were recorded at a higher altitude than they actually were. For example, land data can be filtered to calculate what the same map would look like with the data flown at a user-specified high altitude. Short-wavelength anomalies are suppressed preferentially, where as anomalies with a significant long-wavelength component remain. The fundamental assumption that no anomaly sources exist between the real and simulated (nominal) recording levels holds reasonably well in the Canadian Plains, especially when the nominal recording level is taken to be very much higher than any topography.

Upward continuation is more intuitive than bandpass wavelength filtering, as it is easy to understand while avoiding the need for arbitrarily defined bandpass filters or the possibility of Gibbs ringing. The bulk structure of the upper crust is often revealed by upward continuing potential-field data to a nominal altitude of approximately 20 km. For these magnetic data in northern Alberta, best results were indeed obtained with upward continuation to 20 km. Comparing the upward-continued magnetic data with the low-level data clearly shows which of the anomalies survive the filtering, and thus can be inferred to probably have large rock sources. The anomalies that do not survive the upward continuation lack long-wavelength components and (by inference) large sources.

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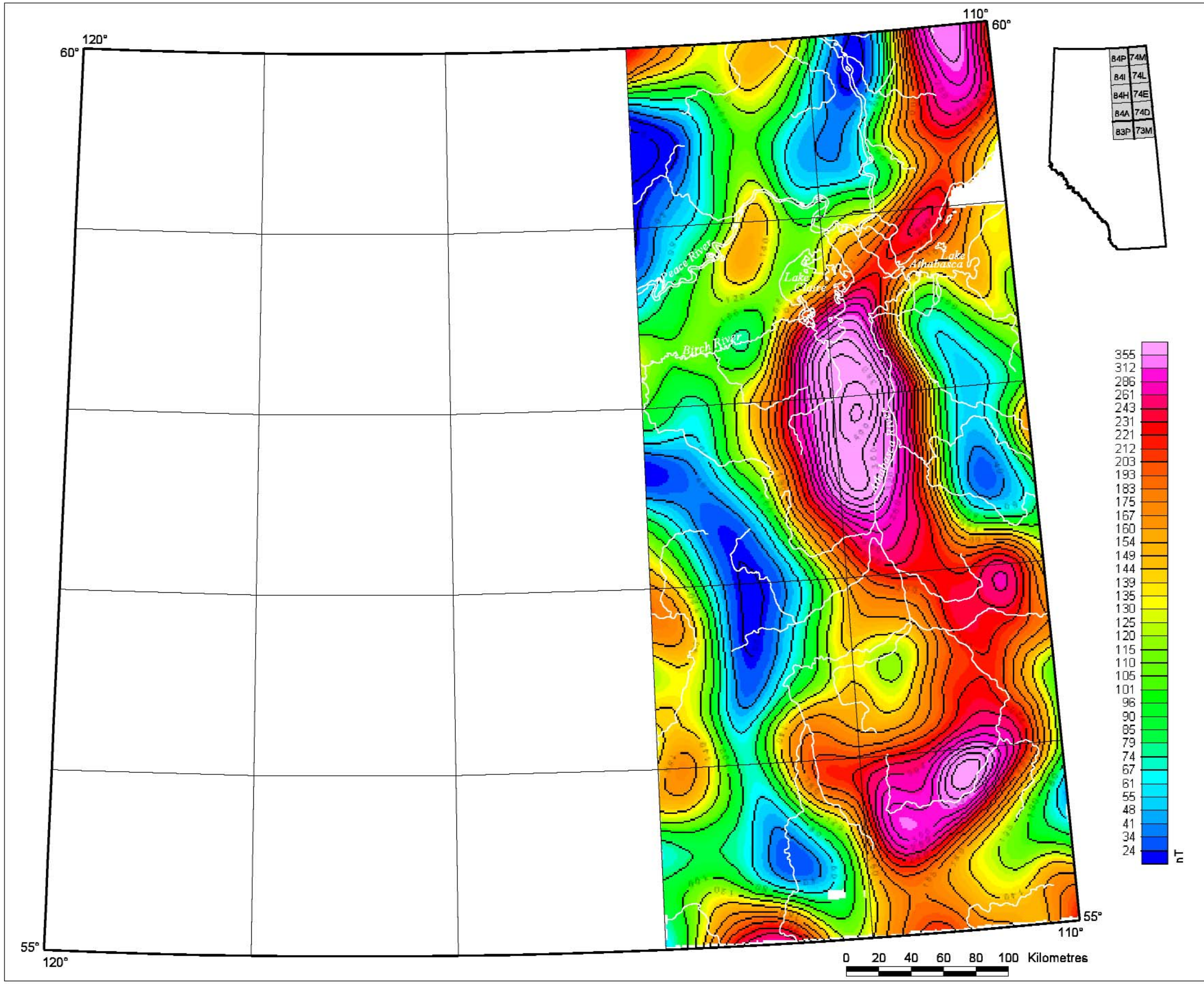
Map 24. Magnetic map of northeastern Alberta (in colour) with superimposed contoured magnetic map upward continued to 20 km.



Upward-Continued Magnetic Map

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Upward continuation is more intuitive than bandpass wavelength filtering, as it is easy to understand while avoiding the need for arbitrarily defined bandpass filters or the possibility of Gibbs ringing. The bulk structure of the upper crust is often revealed by upward continuing potential-field data to a nominal altitude of around 20 km. For these magnetic data in northern Alberta, best results were indeed obtained with upward continuation to 20 km.
Comparing the upward-continued magnetic data with the low-level data clearly shows which of the anomalies survive the filtering, and thus can be inferred to probably have large rock sources. The anomalies that do not survive the upward continuation lack long-wavelength components and (by inference) large sources. Plotted on their own, upward-continued maps vividly reveal the principal anomaly shapes and trends.

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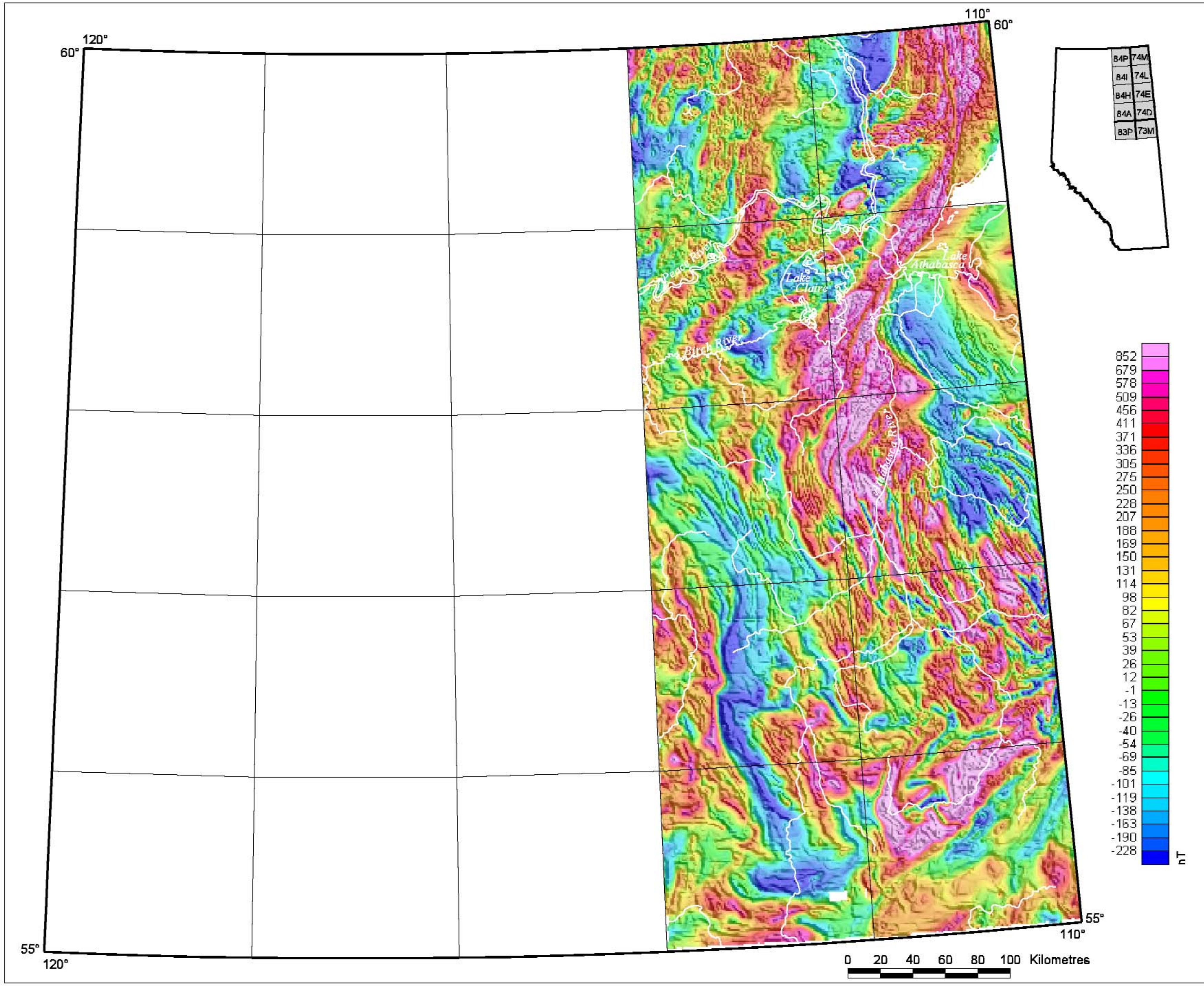
Map 25. Total-field magnetic map of northeastern Alberta upward continued to 20 km.



Magnetic Vertical Shadowgram

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The magnetic field itself is complex: dipolar, non-vertical. The standard unit of magnetic measurements used in exploration geophysics is nanoTesla (nT).
The magnetic data for this study were supplied to the Alberta Geological Survey by the Geological Survey of Canada, with the International Geomagnetic Reference Field reduction that subtracts from the recorded magnetic values the theoretical values computed for an assumed laterally uniform Earth.
To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of shadowgrams.
Shadowgrams, or shaded-relief maps, reveal variations in the dominant anomaly wavelengths and trends between regions. The computational procedure treats a potential-field map as a relief and computes the shadow pattern that would be created if this relief were illuminated by the sun from a user-specified angle. The effect is analogous to taking aerial photographs of a terrain illuminated by the sun. Subtle, local and short-wavelength anomalies are emphasized, whereas broad and smooth features are made less visible.
Sidelighting (illuminating from a non-vertical angle), however acts as a directional filter, highlighting anomalies oriented at high angle to the 'sun' azimuth and suppressing anomalies parallel to the 'sun' azimuth. Such a directional bias is avoided in shadowgrams computed with a vertical sun angle, and the resulting vertical shadowgram simulates a horizontal-gradient map (steepest gradients are darkest). Vertical shadowgrams are vivid when plotted on their own or as layers on top of the colour-coded magnetic maps.
Although vertical shadowgrams are comparable to horizontal-gradient maps overall, no 1:1 identity is to be expected between them. These two computational procedures are dissimilar in their nature and treatment of the data. The output data grids they produce may contain dissimilar local details and dynamic ranges, and they are plotted with different display parameters. With non-identical processing and display techniques, similar anomalies may thus be enhanced and highlighted differently. Beneficially for interpretation, vertical shadowgrams and horizontal-gradient maps are not redundant but complementary. In highlighting similar anomaly shapes and patterns, they reveal different information.

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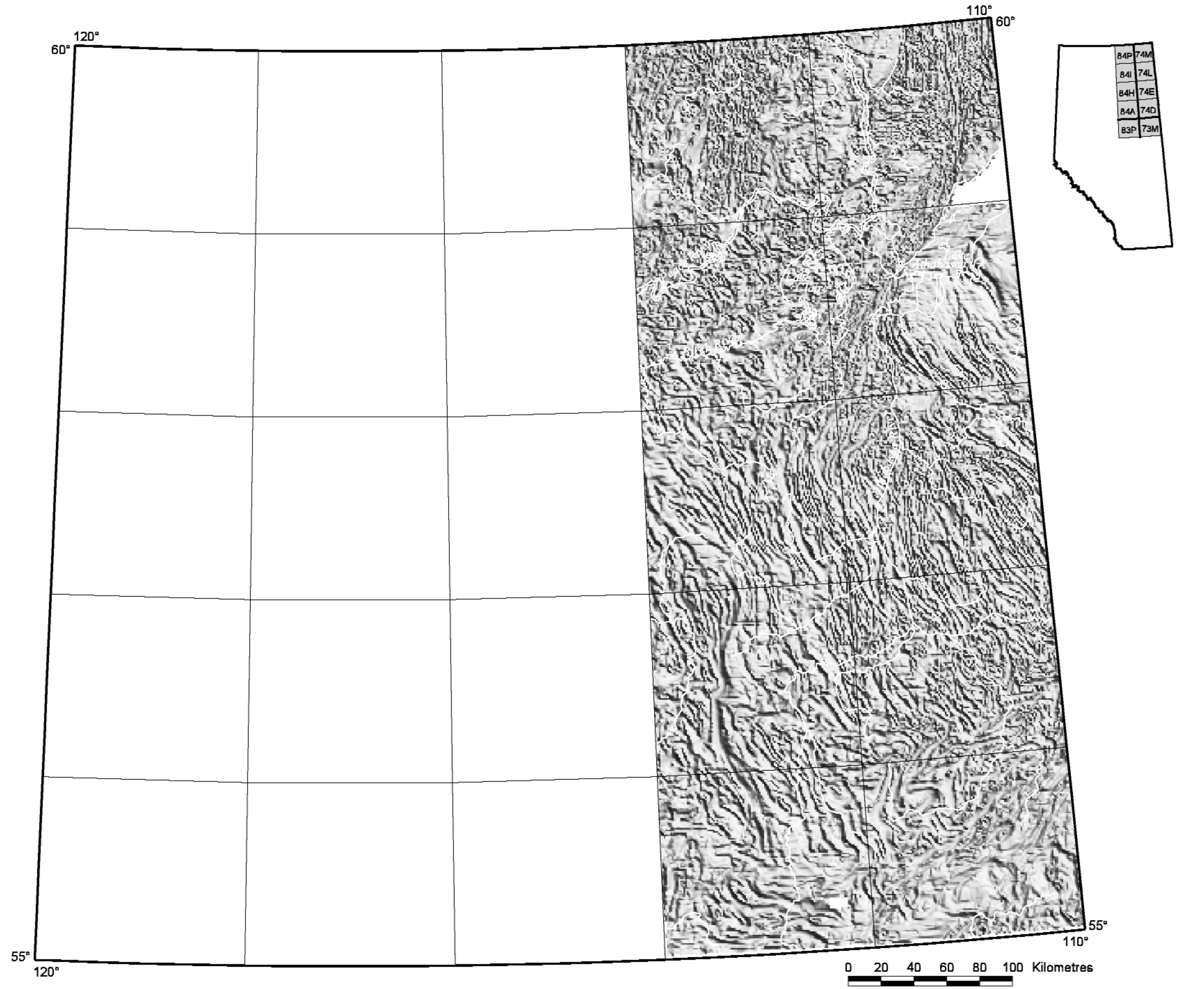
Map 26. Magnetic map of northeastern Alberta with vertical-sun-angle shadowgram.



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To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of shadowgrams.
Shadowgrams, or shaded-relief maps, reveal variations in the dominant anomaly wavelengths and trends between regions. The computational procedure treats a potential-field map as a relief and computes the shadow pattern that would be created if this relief were illuminated by the sun from a user-specified angle. The effect is analogous to taking aerial photographs of a terrain illuminated by the sun. Subtle, local and short-wavelength anomalies are emphasized, whereas broad and smooth features are made less visible.
Sidelighting (illuminating from a non-vertical angle), however, acts as a directional filter, highlighting anomalies oriented at high angle to the 'sun' azimuth and suppressing anomalies parallel to the 'sun' azimuth. Such a directional bias is avoided in shadowgrams computed with a vertical sun angle, and the resulting vertical shadowgram simulates a horizontal-gradient map (steepest gradients are darkest).
Although vertical shadowgrams are comparable to horizontal-gradient maps overall, no 1:1 identity is to be expected between them. These two computational procedures are dissimilar in their nature and treatment of the data. The output data grids they produce may contain dissimilar local details and dynamic ranges, and they are plotted with different display parameters. With non-identical processing and display techniques, similar anomalies may thus be enhanced and highlighted differently. Beneficially for interpretation, vertical shadowgrams and horizontal-gradient maps are not redundant but complementary. In highlighting similar anomaly shapes and patterns, they reveal different information.

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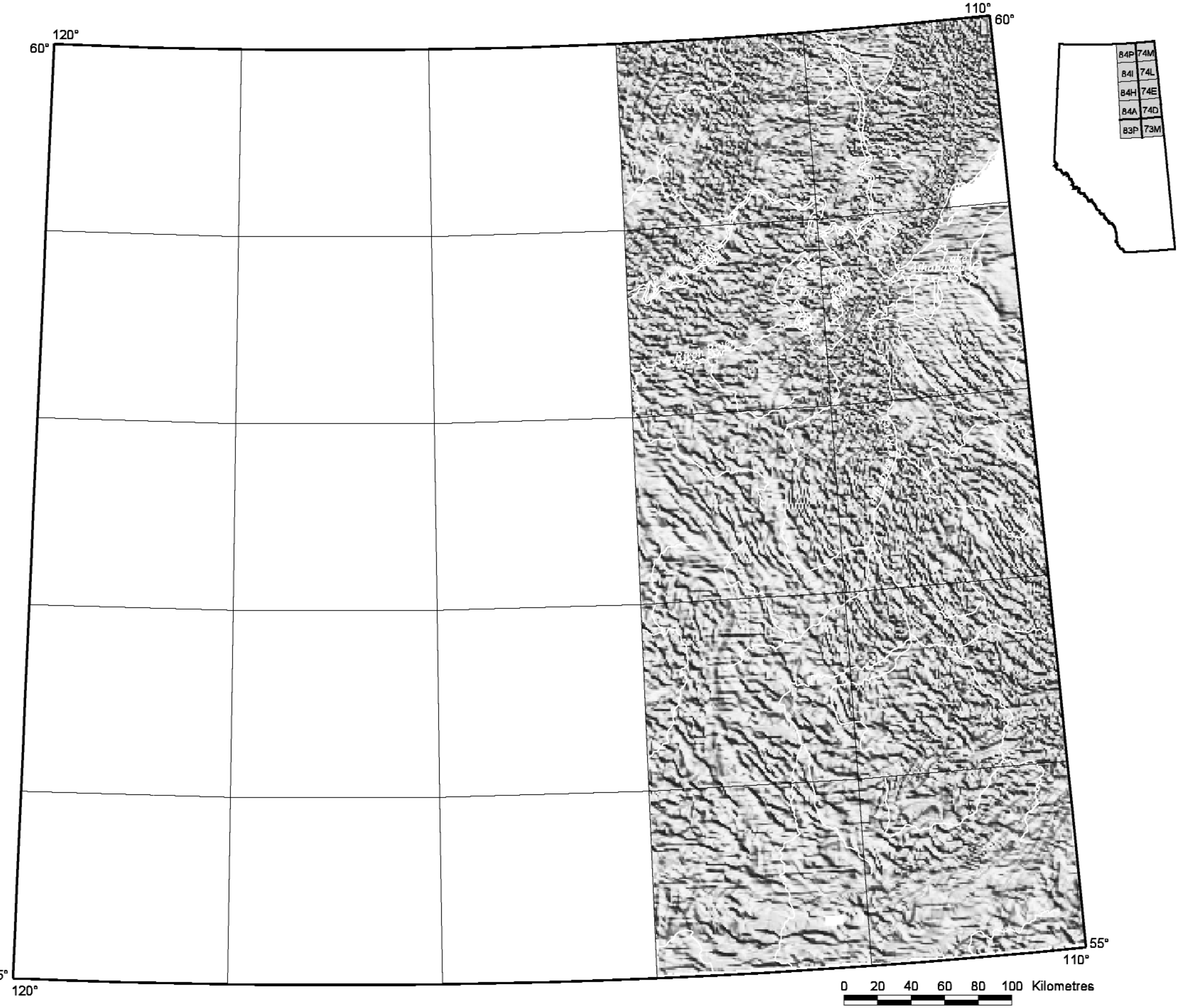
Map 27. Magnetic vertical-sun-angle shadowgram of northeastern Alberta.



Magnetic Shadowgrams

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The effect is analogous to taking aerial photographs of a terrain when the sun is low. Subtle, local and short-wavelength anomalies are emphasized, whereas broad and smooth features are made less visible. Sidelighting also highlights lineaments, especially those oriented at high angles to the 'sun' azimuth. Beause anomalies parallel to the 'sun' azimuth are suppressed, many shadowgrams with various sun angles need to be generated for each dataset to reveal variously oriented anomalies.

To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of shadowgrams.

The optimal 'sun' inclination for this dataset was found by experimentation to be 30° from the horizon. With that angle, a sweep of shadowgrams was generated, with 'sun' illumination from the north, northeast, east, southeast, south, southwest, west and northwest.

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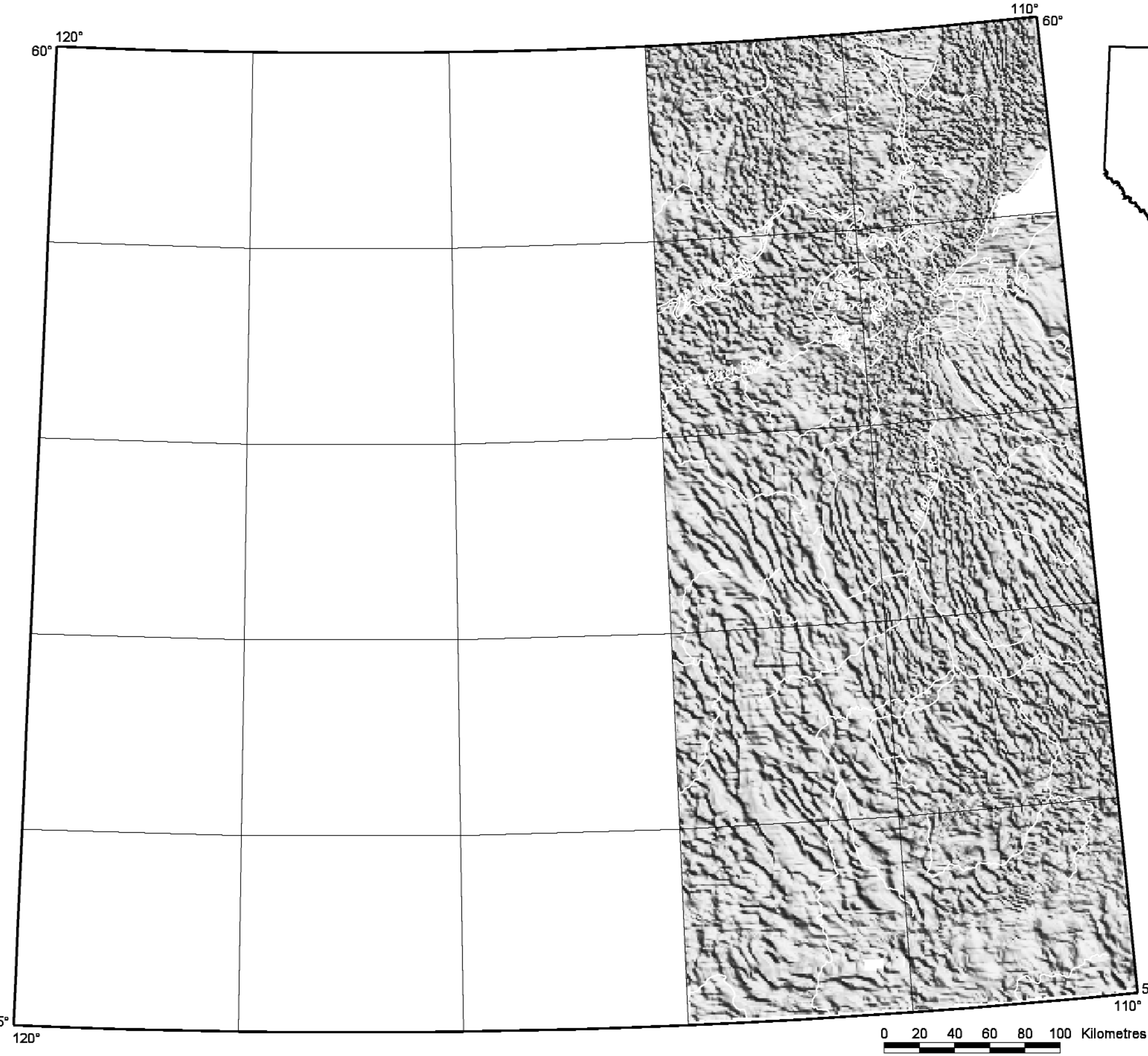
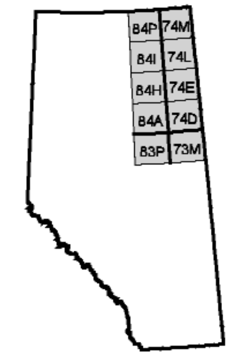
Map 28. Magnetic shadowgram of northeastern Alberta illuminated from the north.





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To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of shadowgrams.
The optimal 'sun' inclination for this dataset was found by experimentation to be 30° from the horizon. With that angle, a sweep of shadowgrams was generated, with 'sun' illumination from the north, northeast, east, southeast, south, southwest, west and northwest.

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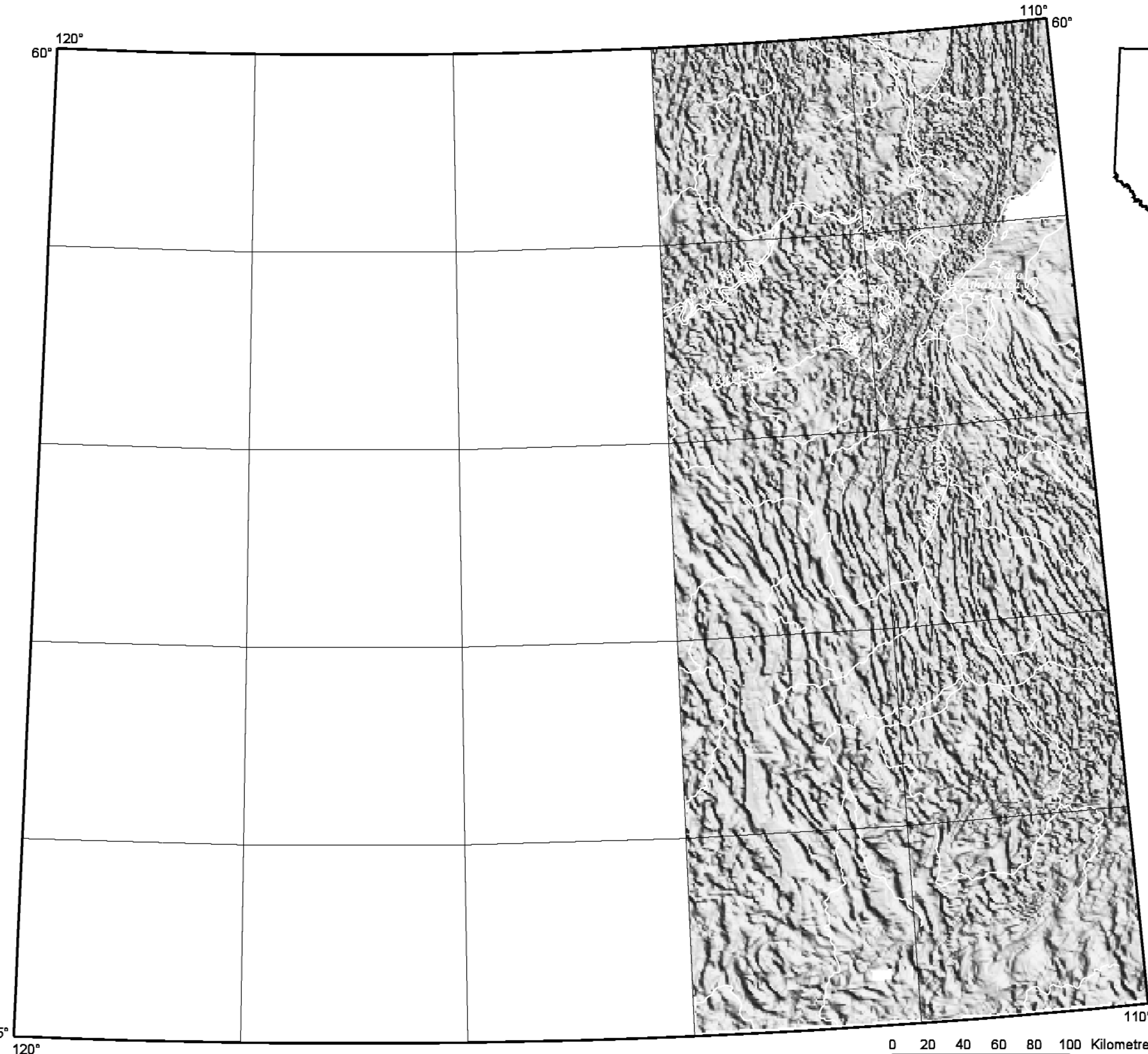
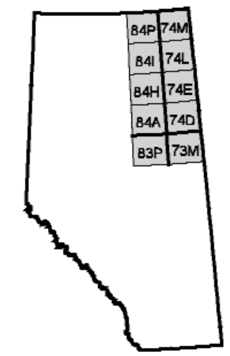
Map 29. Magnetic shadowgram of northeastern Alberta illuminated from the northeast.





Magnetic Shadowgrams

An anomaly is the difference between the observed or measured local value of a potential field and the same field's theoretical value predicted for the same location if the Earth were more laterally uniform than it actually is. Geological sources of geophysical anomalies are variations in specific physical properties of rocks, within or between rock bodies.
An anomaly indicates, indirectly and non-uniquely, some perturbation in the geometric distribution of a particular physical property of underlying rocks. These physical properties are affected by the rocks' entire history as well as present state. By itself, an anomaly says nothing about its rock-made source's nature, lithology or age.
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Rock magnetization is often carried by certain minerals whose distribution may have little relation to the bulk lithological and structural patterns in the rock mass. Rocks lose their ability to support magnetization when heated above the Curie temperature (575 °C for magnetite). In cratonic regions, the Curie isotherm s commonly thought to lie in the lower crust or uppermost mantle (depending on the geothermal gradient), and rocks deeper than this isotherm are not represented in the magnetic anomalies.
The magnetic field itself is complex: dipolar, non-vertical. The standard unit of magnetic measurements used in exploration geophysics is nanoTesla (nT). The magnetic data for this study were supplied to the Alberta Geological Survey by the Geological Survey of Canada, with the International Geomagnetic Reference Field reduction that subtracts from the recorded magnetic values the theoretical values computed for an assumed laterally uniform Earth.
Shadowgrams, or shaded-relief maps, reveal variations in the dominant anomaly wavelengths and trends between regions. The computational procedure treats a potential-field map as a relief and computes the shadow pattern that would be created if this relief were illuminated by the sun from a user-specified angle.
The effect is analogous to taking aerial photographs of a terrain when the sun is low. Subtle, local and short-wavelength anomalies are emphasized, whereas broad and smooth features are made less visible. Sidelighting also highlights lineaments, especially those oriented at high angles to the 'sun' azimuth. Beause anomalies parallel to the 'sun' azimuth are suppressed, many shadowgrams with various sun angles need to be generated for each dataset to reveal variously oriented anomalies.
To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of shadowgrams.
The optimal 'sun' inclination for this dataset was found by experimentation to be 30° from the horizon. With that angle, a sweep of shadowgrams was generated, with 'sun' illumination from the north, northeast, east, southeast, south, southwest, west and northwest.

Henry Lyatsky, Dinu Pana, 2003

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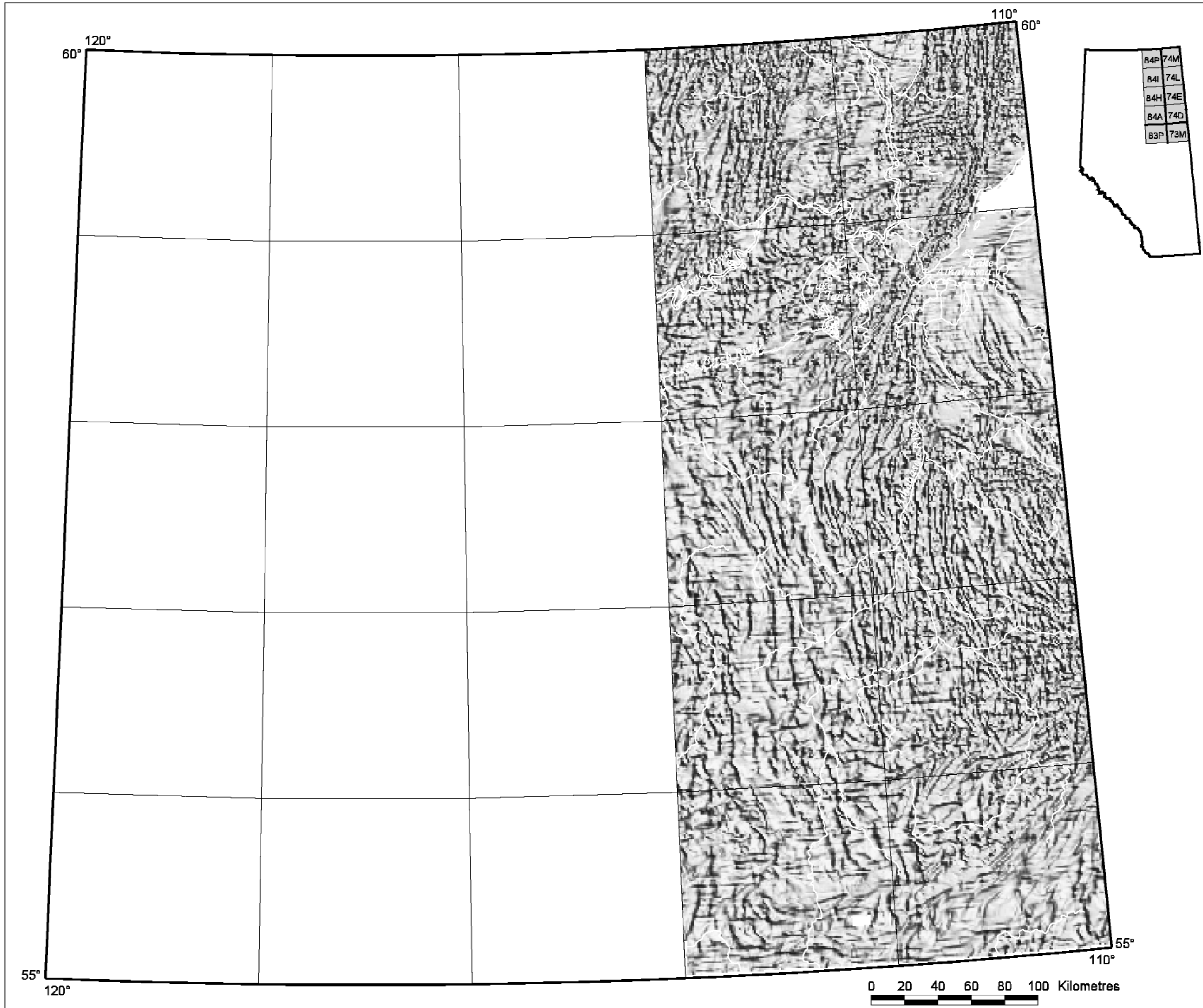
Map 30. Magnetic shadowgram of northeastern Alberta illuminated from the east.



Magnetic Shadowgrams

An anomaly is the difference between the observed or measured local value of a potential field and the same field's theoretical value predicted for the same location if the Earth were more laterally uniform than it actually is. Geological sources of geophysical anomalies are variations in specific physical properties of rocks, within or between rock bodies.

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The magnetic field itself is complex: dipolar, non-vertical. The standard unit of magnetic measurements used in exploration geophysics is nanoTesla (nT). The magnetic data for this study were supplied to the Alberta Geological Survey by the Geological Survey of Canada, with the International Geomagnetic Reference Field reduction that subtracts from the recorded magnetic values the theoretical values computed for an assumed laterally uniform Earth.

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To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of shadowgrams. The optimal 'sun' inclination for this dataset was found by experimentation to be 30° from the horizon. With that angle, a sweep of shadowgrams was generated, with 'sun' illumination from the north, northeast, east, southeast, south, southwest, west and northwest.

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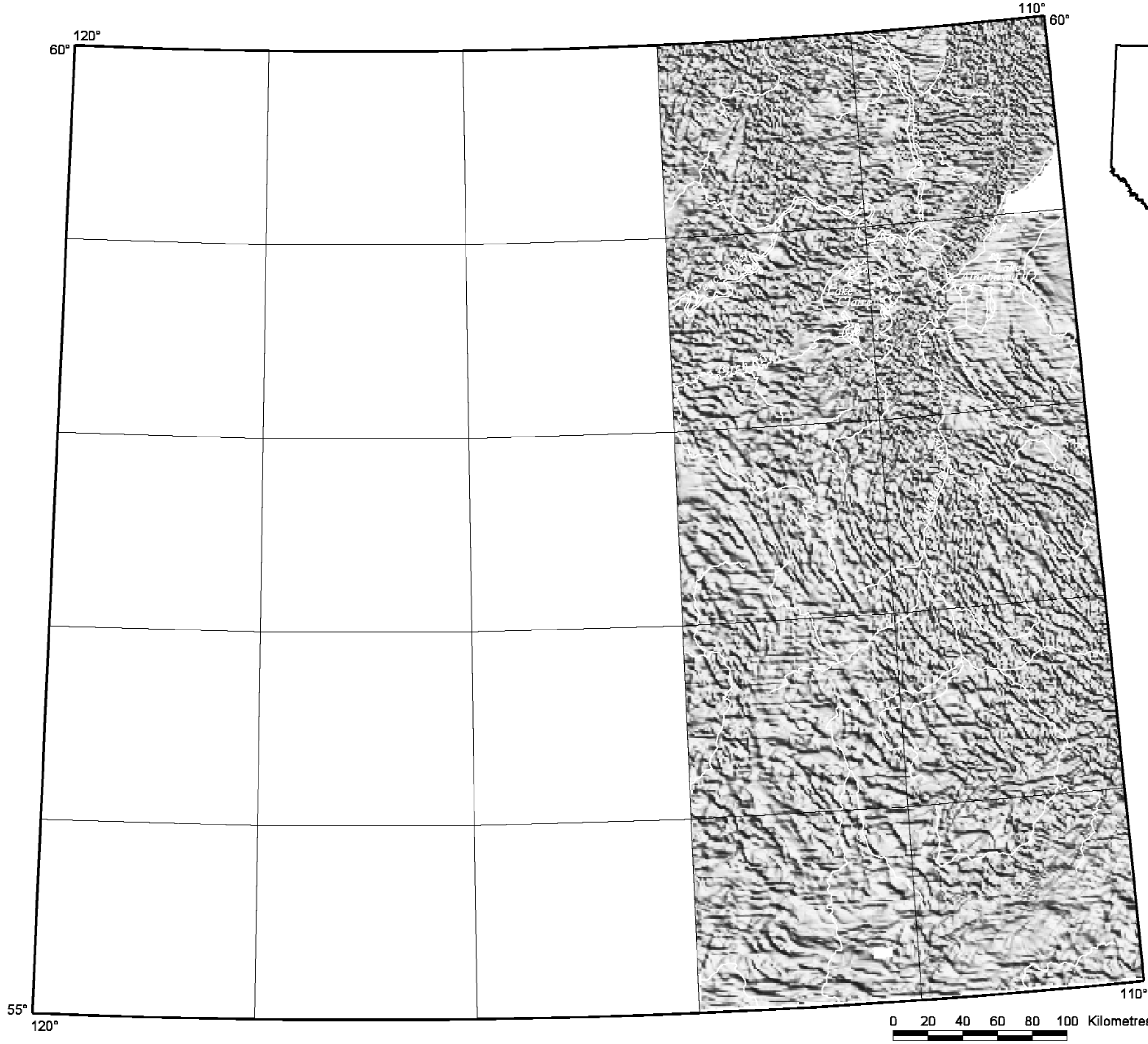
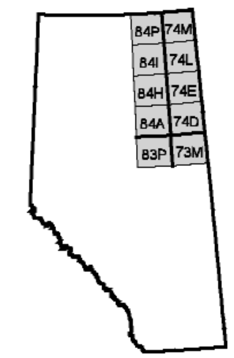
Map 31. Magnetic shadowgram of northeastern Alberta illuminated from the southeast.





Magnetic Shadowgrams

An anomaly is the difference between the observed or measured local value of a potential field and the same field's theoretical value predicted for the same location if the Earth were more laterally uniform than it actually is. Geological sources of geophysical anomalies are variations in specific physical properties of rocks, within or between rock bodies.
An anomaly indicates, indirectly and non-uniquely, some perturbation in the geometric distribution of a particular physical property of underlying rocks. These physical properties are affected by the rocks' entire history as well as present state. By itself, an anomaly says nothing about its rock-made source's nature, lithology or age.
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The magnetic field itself is complex: dipolar, non-vertical. The standard unit of magnetic measurements used in exploration geophysics is nanoTesla (nT). The magnetic data for this study were supplied to the Alberta Geological Survey by the Geological Survey of Canada, with the International Geomagnetic Reference Field reduction that subtracts from the recorded magnetic values the theoretical values computed for an assumed laterally uniform Earth.
Shadowgrams, or shaded-relief maps, reveal variations in the dominant anomaly wavelengths and trends between regions. The computational procedure treats a potential-field map as a relief and computes the shadow pattern that would be created if this relief were illuminated by the sun from a user-specified angle. The effect is analogous to taking aerial photographs of a terrain when the sun is low. Subtle, local and short-wavelength anomalies are emphasized, whereas broad and smooth features are made less visible. Sidelighting also highlights lineaments, especially those oriented at high angles to the 'sun' azimuth. Beause anomalies parallel to the 'sun' azimuth are suppressed, many shadowgrams with various sun angles need to be generated for each dataset to reveal variously oriented anomalies.
To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of shadowgrams. The optimal 'sun' inclination for this dataset was found by experimentation to be 30° from the horizon. With that angle, a sweep of shadowgrams was generated, with 'sun' illumination from the north, northeast, east, southeast, south, southwest, west and northwest.

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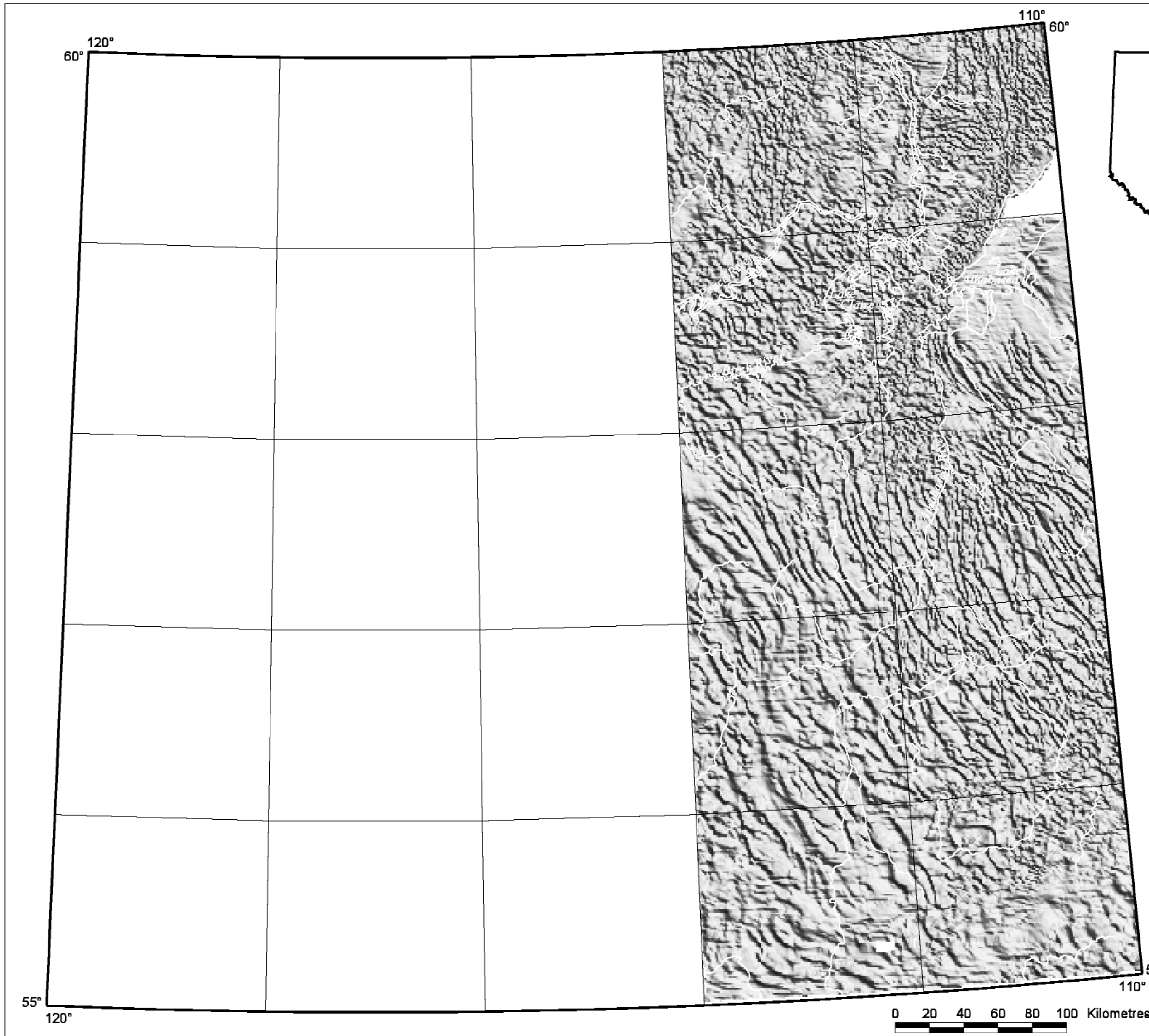
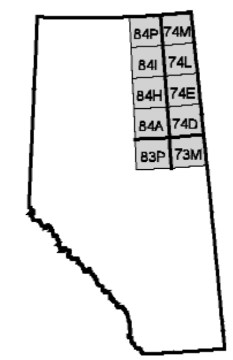
Map 32. Magnetic shadowgram of northeastern Alberta illuminated from the south.





Magnetic Shadowgrams

An anomaly is the difference between the observed or measured local value of a potential field and the same field's theoretical value predicted for the same location if the Earth were more laterally uniform than it actually is. Geological sources of geophysical anomalies are variations in specific physical properties of rocks, within or between rock bodies.
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The magnetic field itself is complex: dipolar, non-vertical. The standard unit of magnetic measurements used in exploration geophysics is nanoTesla (nT). The magnetic data for this study were supplied to the Alberta Geological Survey by the Geological Survey of Canada, with the International Geomagnetic Reference Field reduction that subtracts from the recorded magnetic values the theoretical values computed for an assumed laterally uniform Earth.
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To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of shadowgrams.
The optimal 'sun' inclination for this data set was found by experimentation to be 30° from the horizon. With that angle, a sweep of shadowgrams was generated, with 'sun' illumination from the north, northeast, east, southeast, south, southwest, west and northwest.

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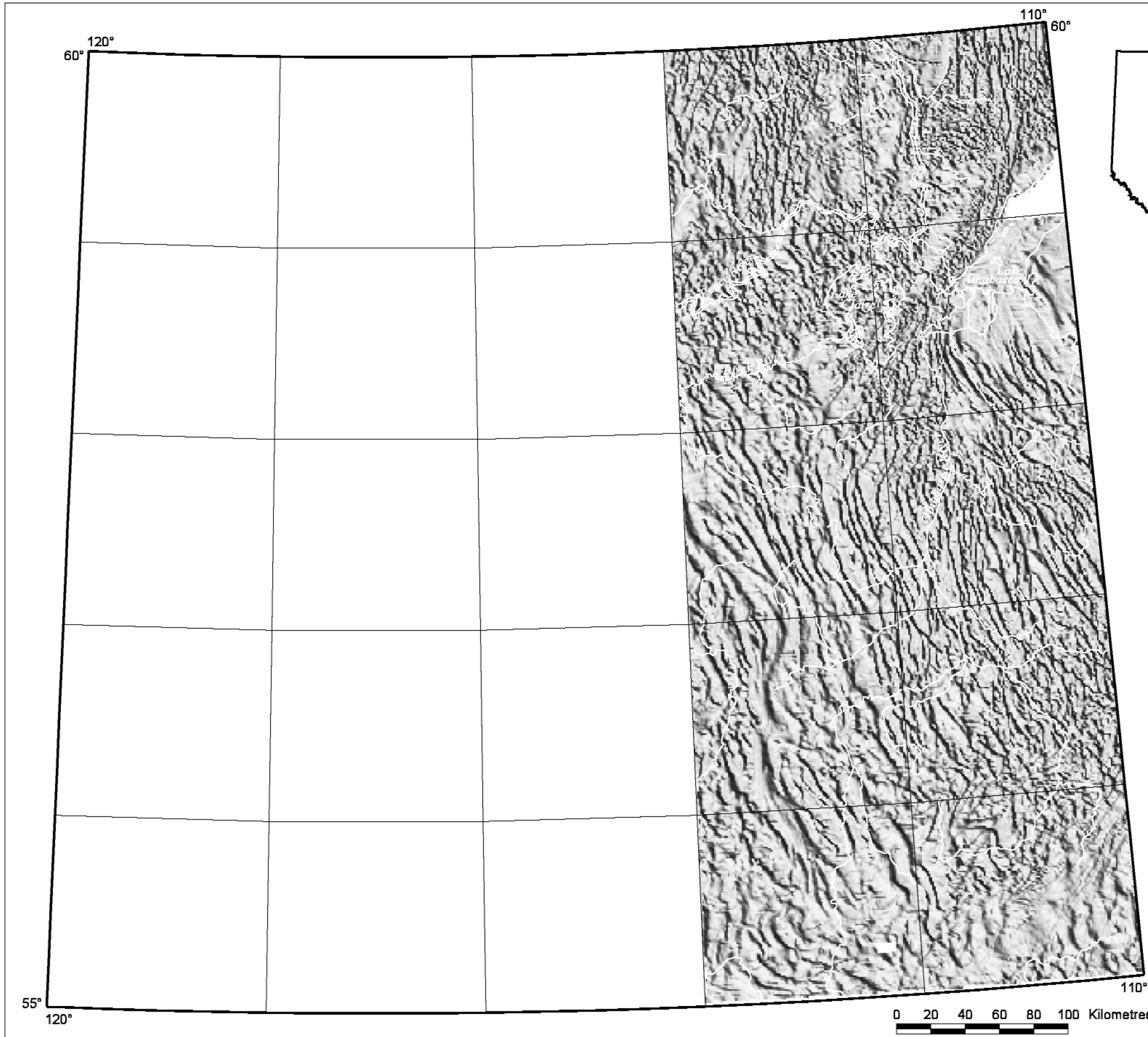
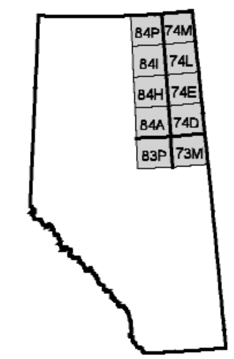
Map 33. Magnetic shadowgram of northeastern Alberta illuminated from the southwest.





Magnetic Shadowgrams

An anomaly is the difference between the observed or measured local value of a potential field and the same field's theoretical value predicted for the same location if the Earth were more laterally uniform than it actually is. Geological sources of geophysical anomalies are variations in specific physical properties of rocks, within or between rock bodies.

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To suppress short-wavelength noise, such as that arising from imperfect flight-line levelling or the cultural noise, the magnetic data were subjected to two passes of the Hanning smoothing convolution filter prior to the creation of shadowgrams.

The optimal 'sun' inclination for this dataset was found by experimentation to be 30° from the horizon. With that angle, a sweep of shadowgrams was generated, with 'sun' illumination from the north, northeast, east, southeast, south, southwest, west and northwest.

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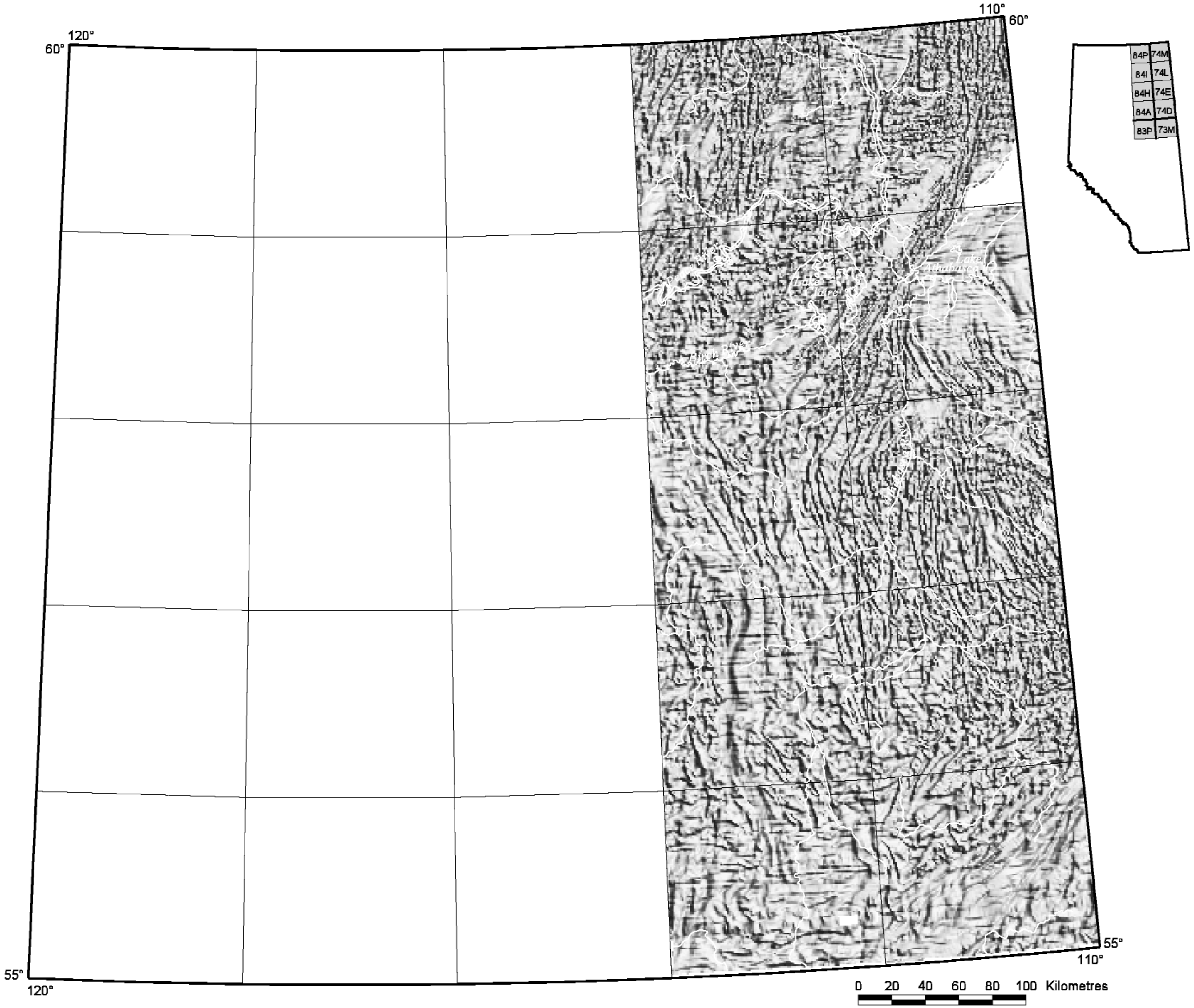
Map 34. Magnetic shadowgram of northeastern Alberta illuminated from the west.



Magnetic Shadowgrams

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Map 35. Magnetic shadowgram of northeastern Alberta illuminated from the northwest.