

MILJØ- OG SAMFUNNSTJENLIGE TUNNELER

Rapport nr:

5

Forundersøkelser

- vurdering av geofysiske anomalier ved
Langvatnet med bruk av Helikoptermålinger



A



Intern rapport nr. 2247



Statens vegvesen

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Summary:				
<p>In June, 1997 and July, 2000, two separate helicopter geophysical surveys were carried out—one over an area in the vicinity of Gran, and the second over an area immediately west of Hurdalssjøen. The purpose of the surveys was to provide geophysical information for improved geological mapping. These data have been used to help evaluate geological conditions related to proposed tunnel construction near Langvatnet, a lake that lies on the eastern edge of the Gran survey area and the western edge of the Hurdal survey area. Faults and fracture zones may appear as linear or curvilinear anomalies in any of the four data types collected, i.e. magnetic, radiometric, electromagnetic, and VLF data. Linear and curvilinear anomalies in the vicinity of Langvatnet were identified in the different data sets, and when plotted together and show three anomaly clusters. One appears on the west side of Langvatnet. A likely source for some of these anomalies is the contact between the metasediments that outcrop 200-300 m west of the lake and the syenitic intrusives of the Oslo igneous province. However, fractures zones mapped in a borehole also occur on this side of the lake and may be a source of some of the anomalies. Two other anomaly clusters near the east end of the proposed tunnel, one cluster about 800 m from the end, the second about 200 m from the end. All three clusters show anomalies in each of the four data types. Most anomalies cut across the proposed tunnel route at a steep angle. A single exception is a magnetic anomaly that approaches the east end of the proposed tunnel at a very shallow angle. Ground geological or geophysical follow up can help clarify the nature of these anomaly clusters.</p>				
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1 INTRODUCTION

In June, 1997, a helicopter geophysical survey was flown by NGU in the vicinity of Gran in Oppland Fylke (Beard, 1998). In July, 2000, a second NGU helicopter geophysical survey was carried out in the area immediately east of the Gran survey, and west of Hurdalssjøen (Beard and Mogaard, 2001). The primary objective of the surveys was to provide geophysical information in order to enhance geological mapping. After the surveys were completed, NGU was approached by Statens Vegvesen and asked to examine the helicopter data in light of proposed tunnel construction near Langvatent, a lake located about 3 km east of the community of Grua in Oppland Fylke (Figure 1). A test borehole beneath the north end of the lake revealed fracture zones on the west side of the lake (Veglaboratoriet, 1998). In this report, different geophysical data sets from both helicopter surveys are examined to see whether these fracture zones are expressed as geophysical anomalies, and whether other geophysical anomalies might indicate other fracture zones along the proposed route of the tunnel.

2 REVIEW OF HELICOPTER GEOPHYSICAL DATA

The types of data that can be collected using NGU's helicopter geophysical systems are magnetic data, electromagnetic (EM) data, very low frequency EM (VLF) data, and radiometric data. Each of these different data sets has the potential to detect faults and fractures; however, each different type of data has its own particular limitations. Radiometric data are sensitive to only the top few centimeters of soil or rock. The presence of water tends to reduce the radiometric signal, making it low over marshy areas, and reducing it to zero over lakes and streams. VLF data are sensitive to shallow, long, linear structures of moderate conductivity. Faults or fractures that are filled with water or conductive clays may appear as VLF anomalies if they lie within about 20 m of the ground surface. VLF transmitters operate at frequencies of between 15-20 kHz. Signals at these moderately high frequencies attenuate rapidly in the earth, therefore deeper structures will not be detected. NGU's EM system operates at five different frequencies between 34300 Hz and 880 Hz. The lowest frequency has the capability of detecting conductive faults or fractures down to a depth of about 100 m. Lakes with moderately conductive water, or conductive clay layers with thickness of several meters have the effect of obscuring the EM signal produced by conductive structures below the conductive layers. Magnetometers can easily detect structures having anomalous magnetic properties at depths hundreds of meters. However, if a fault or fracture does not contain appreciably more or less magnetic material than the surrounding rock, it will not produce a magnetic anomaly.



10 km

Fig. 1. Location map showing Langvatnet (N-S lake in center of ellipse) and the approximate trace of the tunnel (thick black line inside ellipse). From Mjøsa sheet, 1:250 000 vegkart over Norge (Statens Vegvesen, 1977).

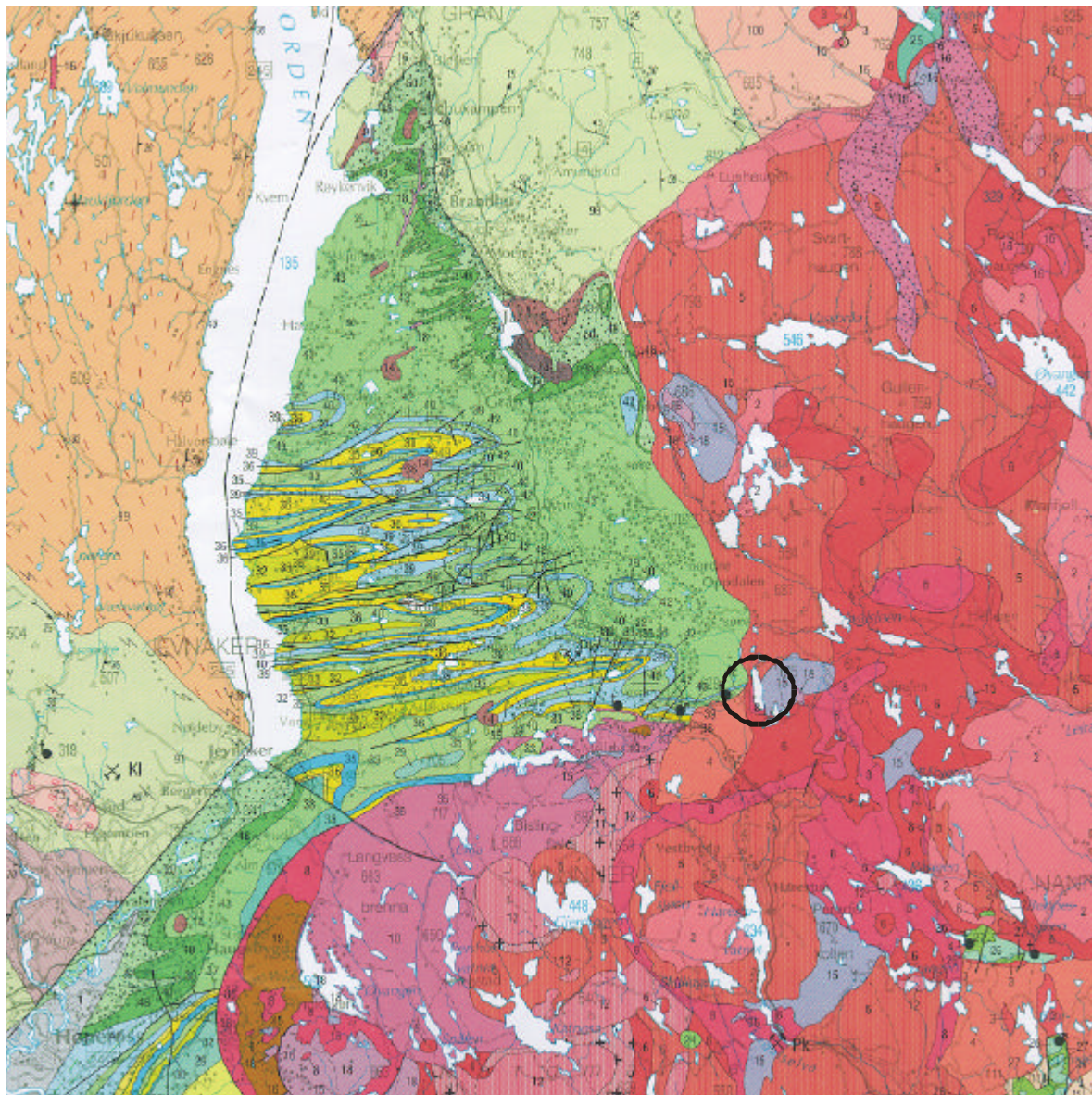
3 GEOPHYSICAL DATA INTERPRETATION

The general geology of the area can be seen in NGU's 1:250 000 scale bedrock geology map over Hamar (Nordgulen, 1999), a portion of which is shown in Figure 2. Langvatnet lake lies very near boundary between two very distinct geological areas. About 250 m west of the lake's western shore is the boundary between Cambro-Silurian metasediments that extend westward and the Permian intrusive and extrusive rocks of the Oslo igneous province. The lake lies completely within the igneous zone. Although accurate in a general sense, the scale of the Hamar map is too large to encompass much detail. Shown in Figure 3 is the total magnetic field map from NGU's 1998 and 2000 Hurdal surveys. Centered about 6 km northwest from Langvatnet is the magnetic anomaly of a ring structure having an east-west width of almost 8 km. This major feature does not appear on the Hamar geological map, but the anomaly is probably an expression of an igneous intrusion. Judging from the magnetic anomalies around Langvatnet, the anomaly produced by the ring structure appears to be sufficiently removed as to have little influence in the area of the proposed tunnel.

In this section I examine subsets of the Gran and Hurdal data sets in the vicinity of the proposed tunnel. From each data set I chose anomalies that were linear or curvilinear and so might have sources in linear or curvilinear structures such as faults, fractures, contacts, or dikes. Each of these data sets and anomalies are shown as separate figures in the Appendix. I then grouped these anomalies by data type: magnetic, radiometric, EM, or VLF. Details on the instruments used to make the geophysical measurements and on the processing of the data can be found in the NGU report of the Hurdal survey (Beard and Mogaard, 2001) and on the Gran survey (Beard, 1998). The final step was to compile all of the different anomalies into a single map.

3.1 Magnetic anomalies

The magnetic anomaly map shown in Figure 4 was produced from total magnetic field data and the vertical second derivative of these data. These data sets and anomalies are shown in Figures A1-A4. Many of the anomalies on the west side of the lake appear related to the geological contact between the metasediments in the west and the syenitic intrusives on the west side of the lake. However, anomaly M3 is too close to the western shore of the lake and too far south to be related to the contact. However, it does not appear to intersect the proposed tunnel. Anomaly M7 is a magnetic low in the middle of the north part of the lake and could represent a fracture zone, or could simply be the low anomaly between two positively magnetized dikes. Anomalies M9 and M12 are almost coincident with the eastern portion of the tunnel. No other data sets show a similarly oriented anomaly in this location; however, the sub-parallel orientation of the anomaly suggests geological or geophysical follow up is warranted.



10 km

Fig. 2. General geology of the area around Lanvatnet (circled). Green coded rocks to the west of Langvatnet are metasediments. Reds are Permian intrusives. The gray shaded area immediately to the east of Langvatnet represents ignimbrites and lava flows. From 1:250 000 bergrunnskart over Hamar (Nordgulen, 1999).

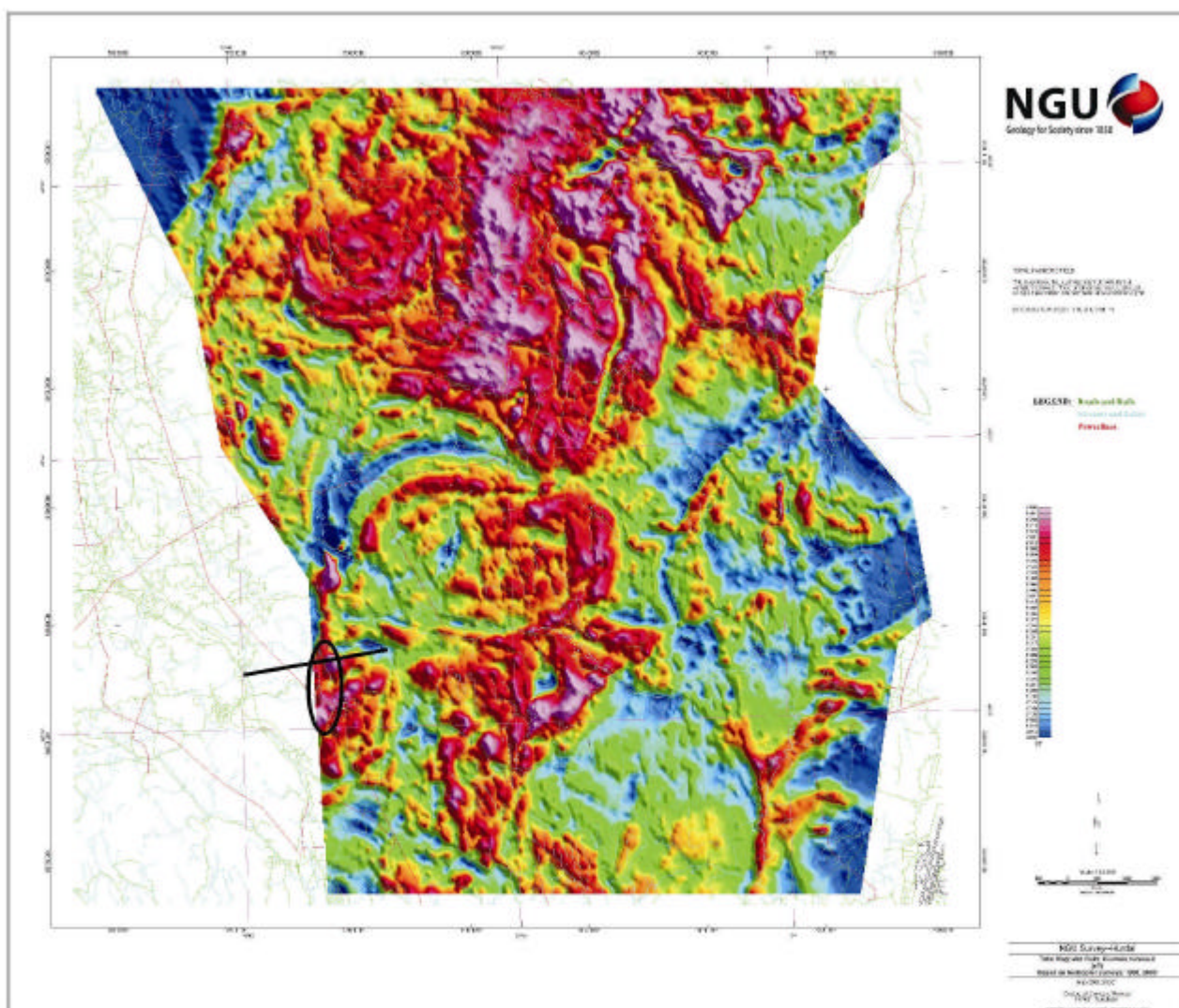


Fig. 3. Magnetic field from Hamar survey (Beard and Mogaard, 2001) showing oval total field anomaly immediately northeast of Lanvatnet (inside ellipse). The approximate trace of the tunnel is shown by the thick black line. On this and following figures, green lines represent roads and railways, red represents power lines, and blue represents lakes, rivers, and streams.

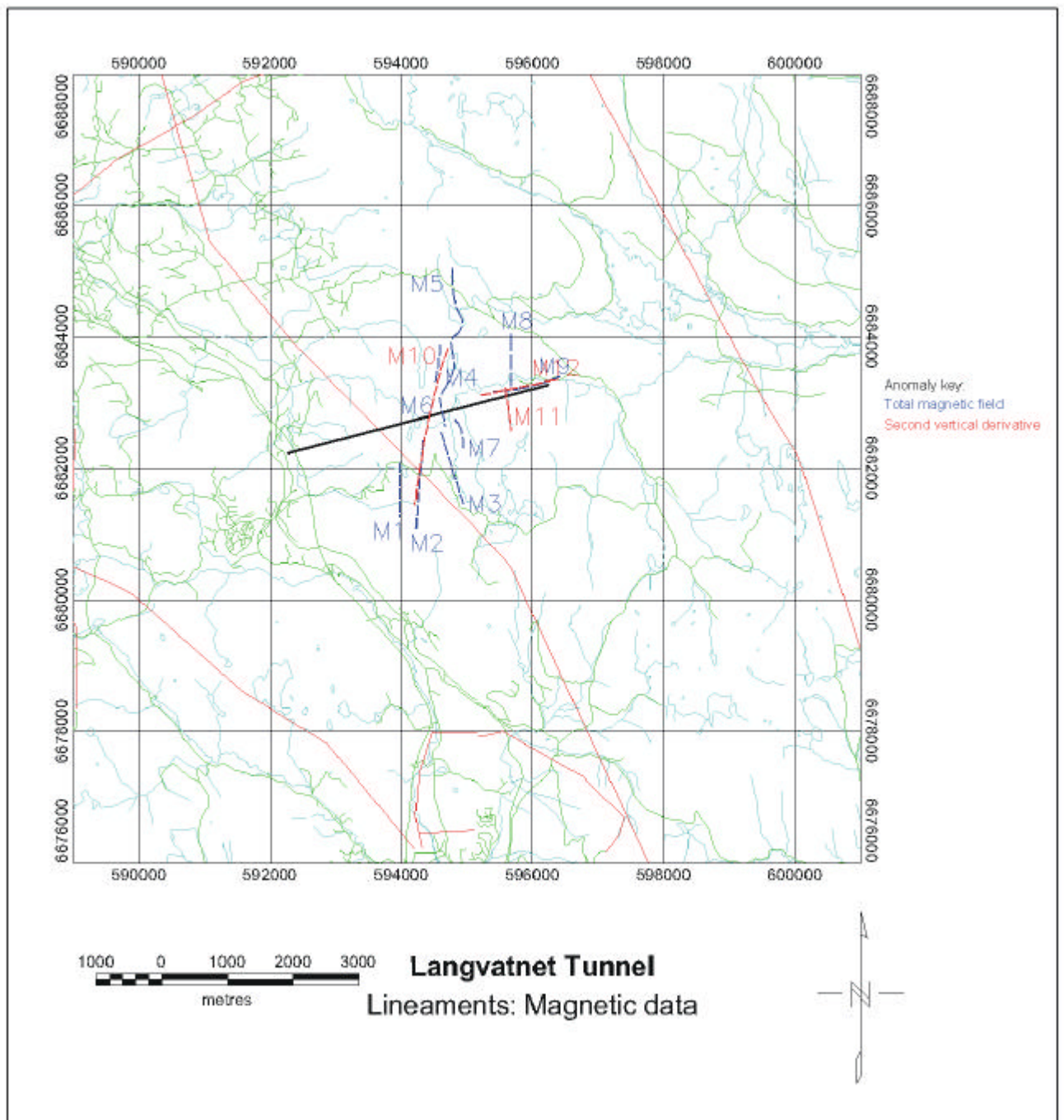


Fig. 4. Map showing linear and curvilinear magnetic field anomalies in the vicinity of Langvatnet. Key to features: red = power lines, green = roads and railways, blue = lakes, rivers, and streams.

3.2 Radiometric anomalies

Figures A5-A12 show the data and anomalies from the four different radiometric channels: total counts, potassium, thorium, and uranium. These anomalies are combined in Figure 5. The large cluster of anomalies west of the lake dominates the figure and is probably an expression of the metasediment-syenite contact. Outcropping fracture zones may also produce radiometric anomalies through alteration of materials in the fractures. Anomaly R8 cuts the trace of the proposed tunnel about 600 m from its east end. It is coincident with a relatively straight stream and could indicate the presence of a fracture zone. Several more radiometric anomalies are found near the east end of the proposed tunnel.

3.3 Electromagnetic anomalies

Electromagnetic data were not collected in the Gran survey, so the west end of the tunnel trace is not covered by EM. The Hurdal survey collected EM data for five different frequencies and two different coil orientations. Frequencies 980 Hz and 7000 Hz use the vertical coaxial coil orientation (VCA). This orientation is sensitive to vertically oriented conductors. The horizontal coplanar coil orientation (HCP) was used with frequencies 880 Hz, 6600 Hz, and 34100 Hz. This orientation is more sensitive to flat lying conductive bodies. In general, the lower the frequency, the deeper the depth of investigation. The lowest frequencies may detect conductors at depths of about 100 m.

Shown in Figure 6 is a compilation of anomalies chosen from the in phase and quadrature components for the five frequencies. As can be seen in Figures A13-A17, most of the anomalies are quadrature component anomalies. In phase anomalies were detected only with the 980 Hz VCA coils. Anomaly E7 is a resistive anomaly, possibly indicating a thick dike. Diabase dikes were encountered in the test bore beneath Langvatnet (Vegslaboratoriet, 1998). Anomalies E12 and E14 are nearly coincident quadrature and in phase anomalies from the 980 Hz VCA coils. E14 represents an in phase high whereas E12 represents a quadrature low. This combination at the same location is indicative of a highly conductive vertically oriented plate. A mineralized fracture zone could cause such an anomaly. These anomalies disappear at the north end of the lake, possibly obscured by the moderately conductive water layer. EM anomalies occur regularly along the eastern half of the tunnel trace, but a distinct cluster occurs near the east end, and is coincident with a cluster of radiometric anomalies. This could indicate a zone of outcropping fractures.

3.4 VLF anomalies

Ten different VLF anomalies are shown in Figures A18 –A21. These are shown combined in one map in Figure 7. Of the ten VLF anomalies, only three line up with anomalies from other data sets. V7 is coincident with several other north-south trending anomalies near the

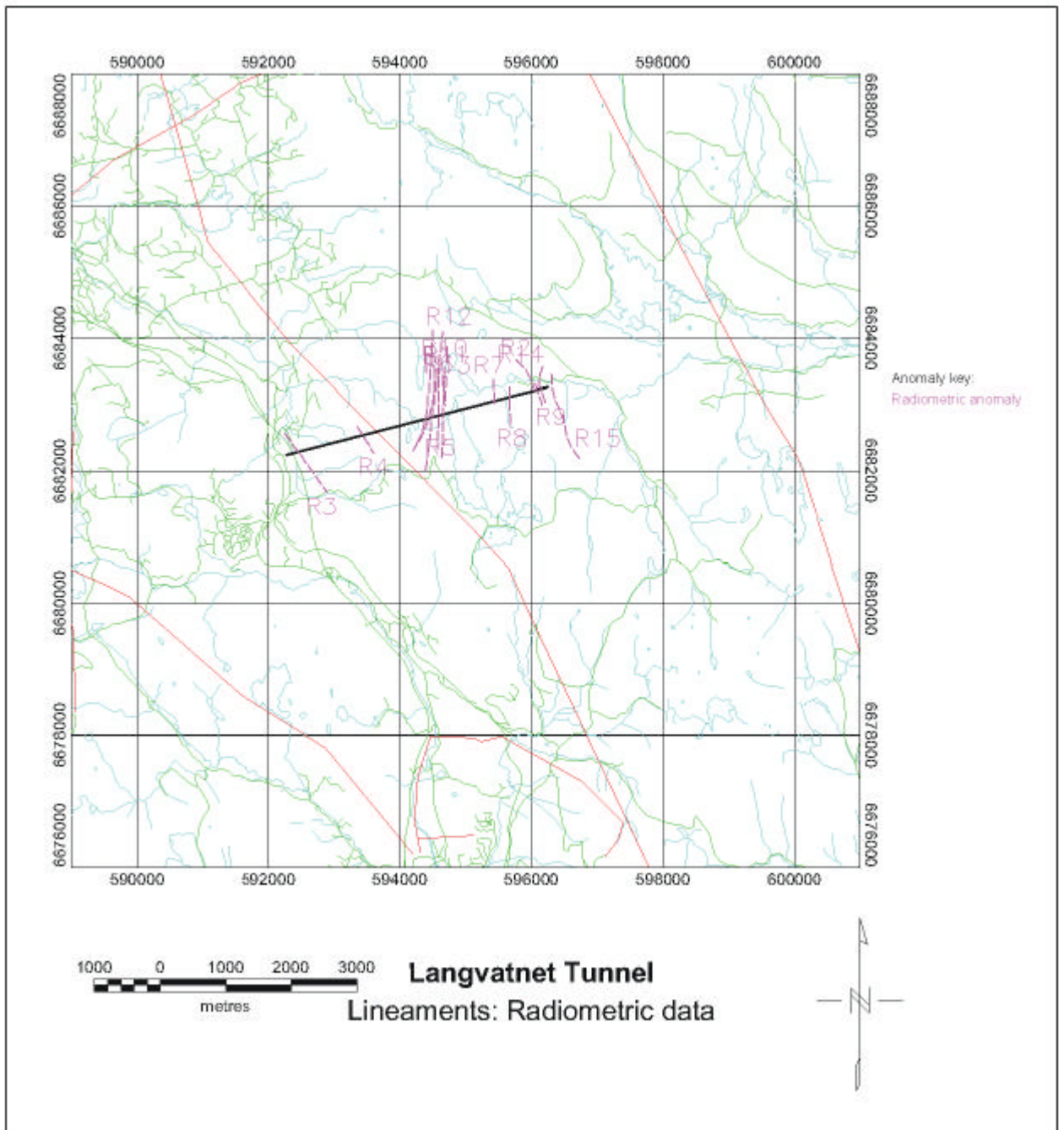


Fig. 5. Map showing linear and curvilinear radiometric anomalies in the vicinity of Langvatnet.

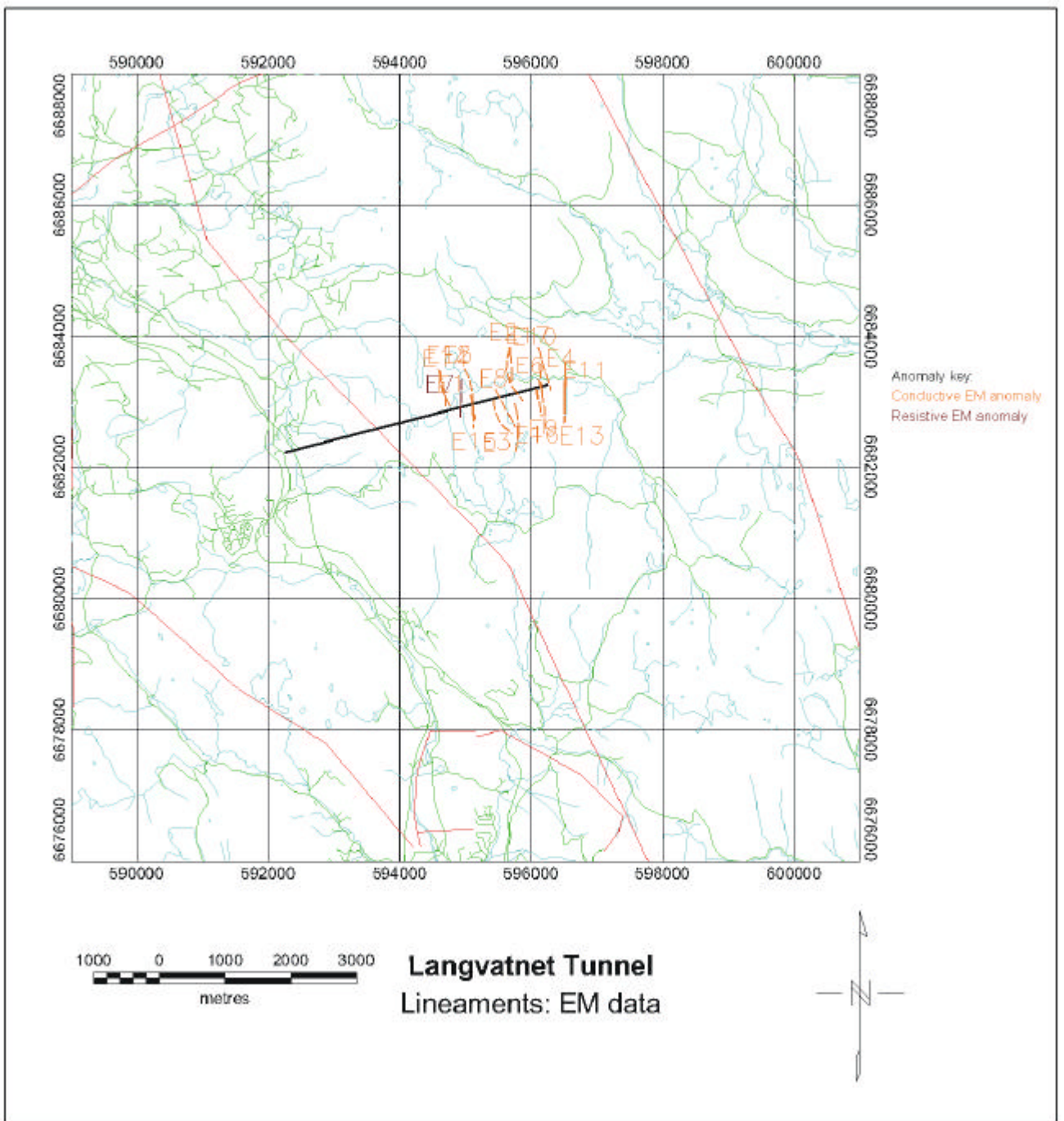


Fig. 6. Map showing linear and curvilinear anomalies from EM data.

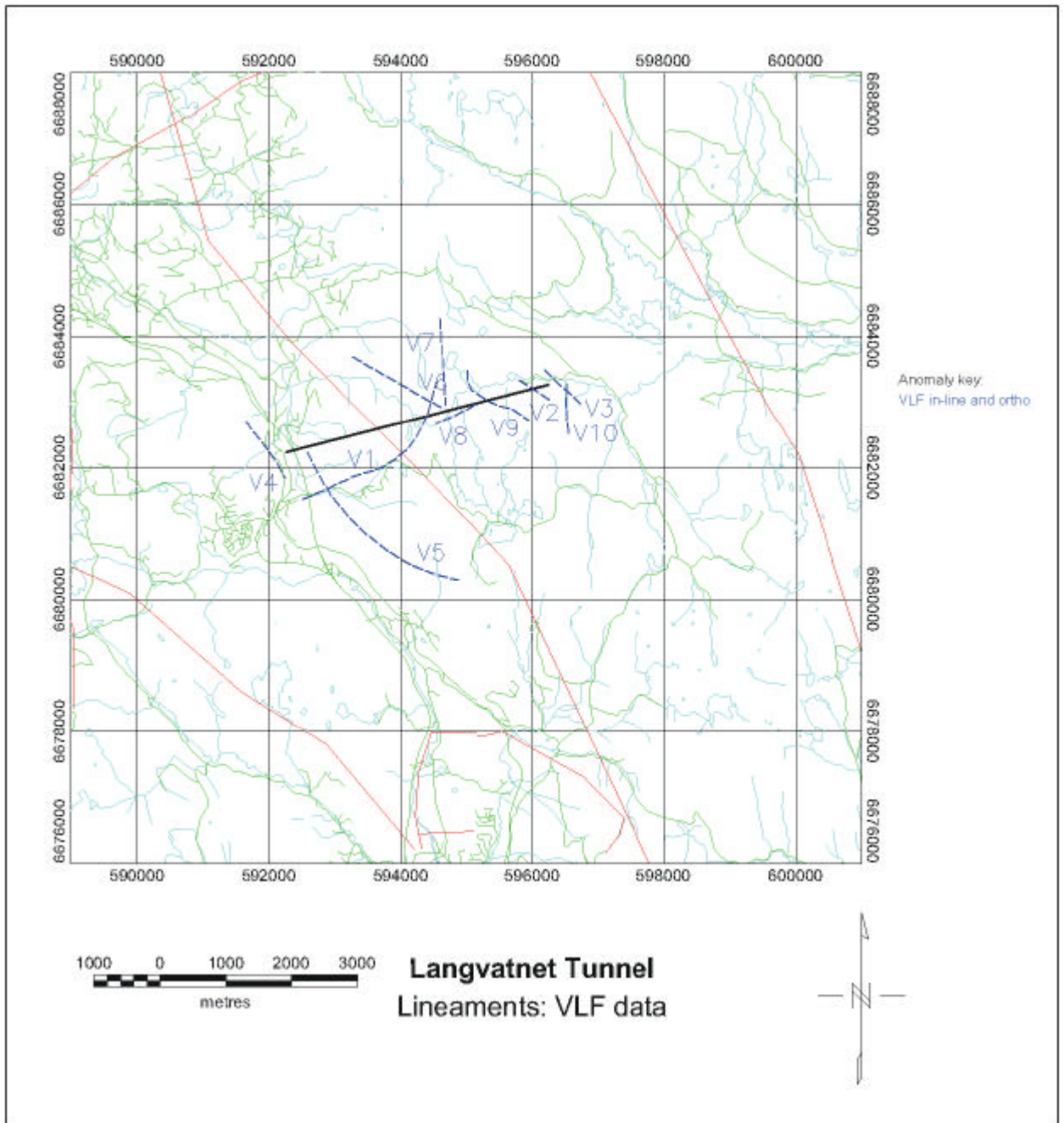


Fig. 7. Map showing linear and curvilinear anomalies from VLF data.

northwest corner of Langvatnet, and may indicate a shallow fracture zone. Anomaly V5, near the extreme west end of the proposed tunnel, merges into radiometric anomaly R3. About 250-300 m east of the east end of the proposed tunnel anomaly V10 is aligned with conductive EM anomalies E13 and E11. All three of these anomalies line up with a small stream, and they likely mark a fracture zone or fault. These anomalies lie beyond the proposed tunnel trace.

4 DISCUSSION AND CONCLUSIONS

Figure 8 and Map 01 show a combined plot of all the anomalies: 12 magnetic, 15 radiometric, 17 EM, and 10 VLF. Most of the anomalies cut across the tunnel trace at steep angles. Only three anomalies—V8, M9, and M12—cut the tunnel trace at shallow angles. The largest cluster of anomalies occurs on the northwest side of Langvatnet. Some of these appear related to the geological contact between the igneous intrusives around Langvatnet and the metasediments 200-300 m to the east of the western lakeshore. However, other anomalies seem too close to the shoreline to be produced by the contact. The source of the anomalies is unknown, but may be related to fractures encountered in a drill hole beneath the lake (Veglaboratoriet, 1998).

Besides the cluster of anomalies near the western lakeshore, few anomalies appear west of the lake. In part this is illusory because EM data was not collected in the Gran survey. Nonetheless, markedly fewer VLF, radiometric, and magnetic anomalies appear in the Gran data (west area) than in the Hurdal data. Either there are fewer large faults and fractures in this area than east of the lake, or the structures do not have a strong geophysical expression.

The Gran survey lines were flown north-south, whereas the Hurdal survey lines were oriented east-west. Filters applied during processing to remove level error along the flight lines can also reduce or remove long, narrow, but real anomalies that occur along the flight line direction. This means long, linear anomalies trending north-south could be obscured in the Gran data, and similar east-west trending anomalies could be obscured in the Hurdal data.

Steep topography can cause anomalies. However, no linear anomalies strongly correlate with topographic relief except for the anomalies on the west side of Langvatnet. Here, a plateau west of the lake steeply slopes downward toward the lake. This could cause anomalies in the east-west Hurdal lines partly because the helicopter's height above ground level may change considerably over rough topography. However, most of the anomalies come from the Gran survey, which was flown north-south. In this case the helicopter has an easier time following topographic contours. Although the slope can still effect the various sensors, strong anomalies such as those appearing west of the lake probably have a geologic origin.

East of the lake there are numerous scattered anomalies, but two clusters tend to stand out. One cluster is centered at UTM coordinates 595570 E and 6683090 N. This is located about 700 m from where the tunnel trace crosses the east shoreline of Langvatnet. The anomalies occupy a zone about 300 m wide, consist of radiometric, magnetic, and EM anomalies, and probably have several different sources. The second cluster of anomalies east of the lake lies almost at the end of the proposed tunnel trace and consists of EM and radiometric anomalies in a zone less than 150 m wide. The zone, centered on 596100 E and 6683220 N, lies about 200 m from the east termination of the proposed tunnel. These three zones merit further attention prior to tunnel construction.

5 REFERENCES

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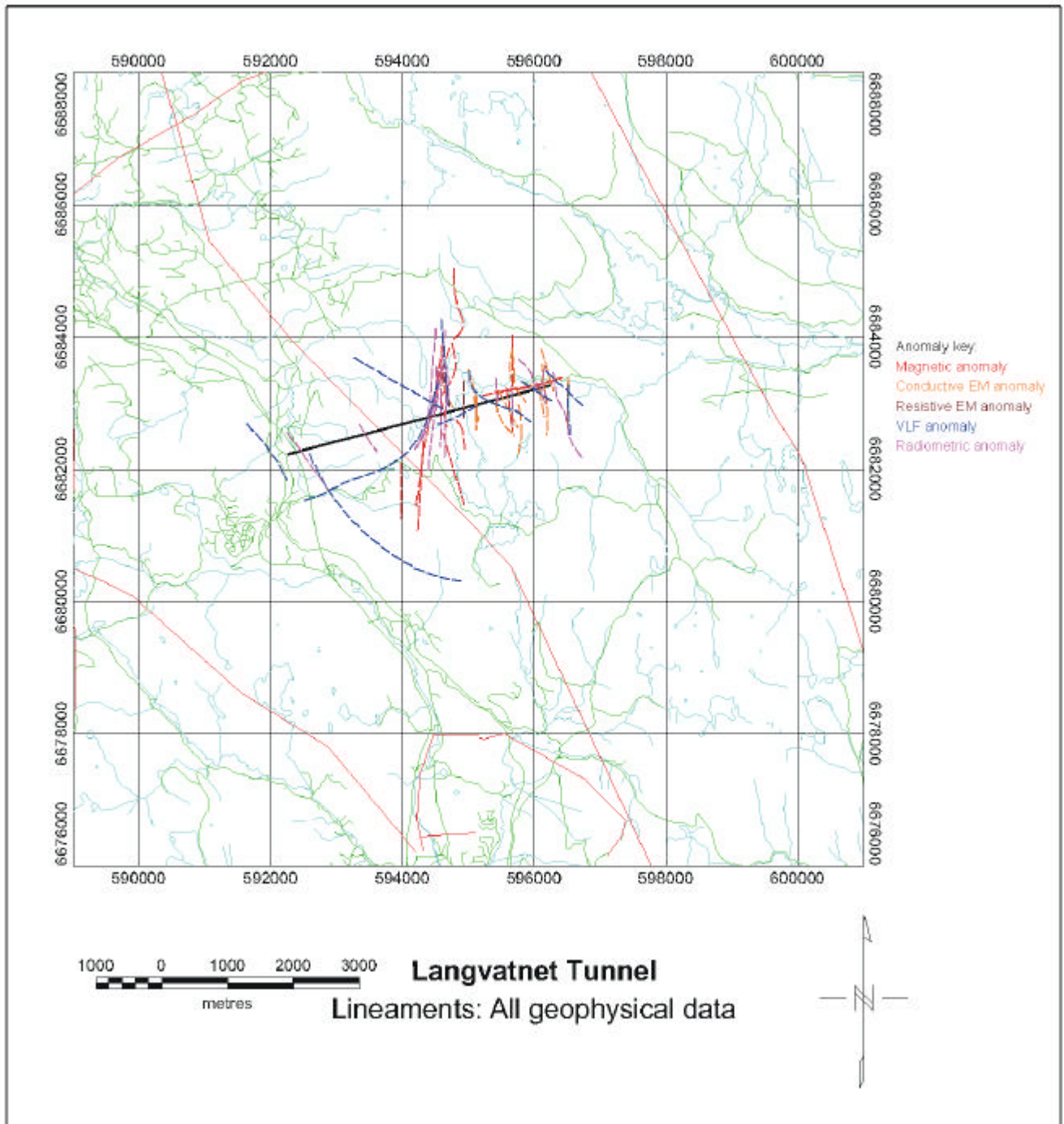


Fig. 8. Map showing linear and curvilinear anomalies from all data sets.

6 APPENDIX

The following 21 figures show the data and the anomaly choices used to construct the anomaly maps shown in Figures 4.8. Only linear or curvilinear anomalies were chosen because these are the anomalies most likely to represent structures relevant to tunnel construction: faults, fractures, contacts, or dikes. Only anomalies in the immediate vicinity of the proposed tunnel trace were marked; however, it was not required that the anomaly cut the tunnel trace. The proposed tunnel trace is shown in each figure as a black straight line. Anomalies are labelled dashed lines or curves. Green lines represent roads and railways; blue represents lakes, rivers, and streams; and red represents power lines. Figures A13-A17 show EM anomalies from the Hurdal survey (east side) only. No EM data was collected in the Gran survey (west side).

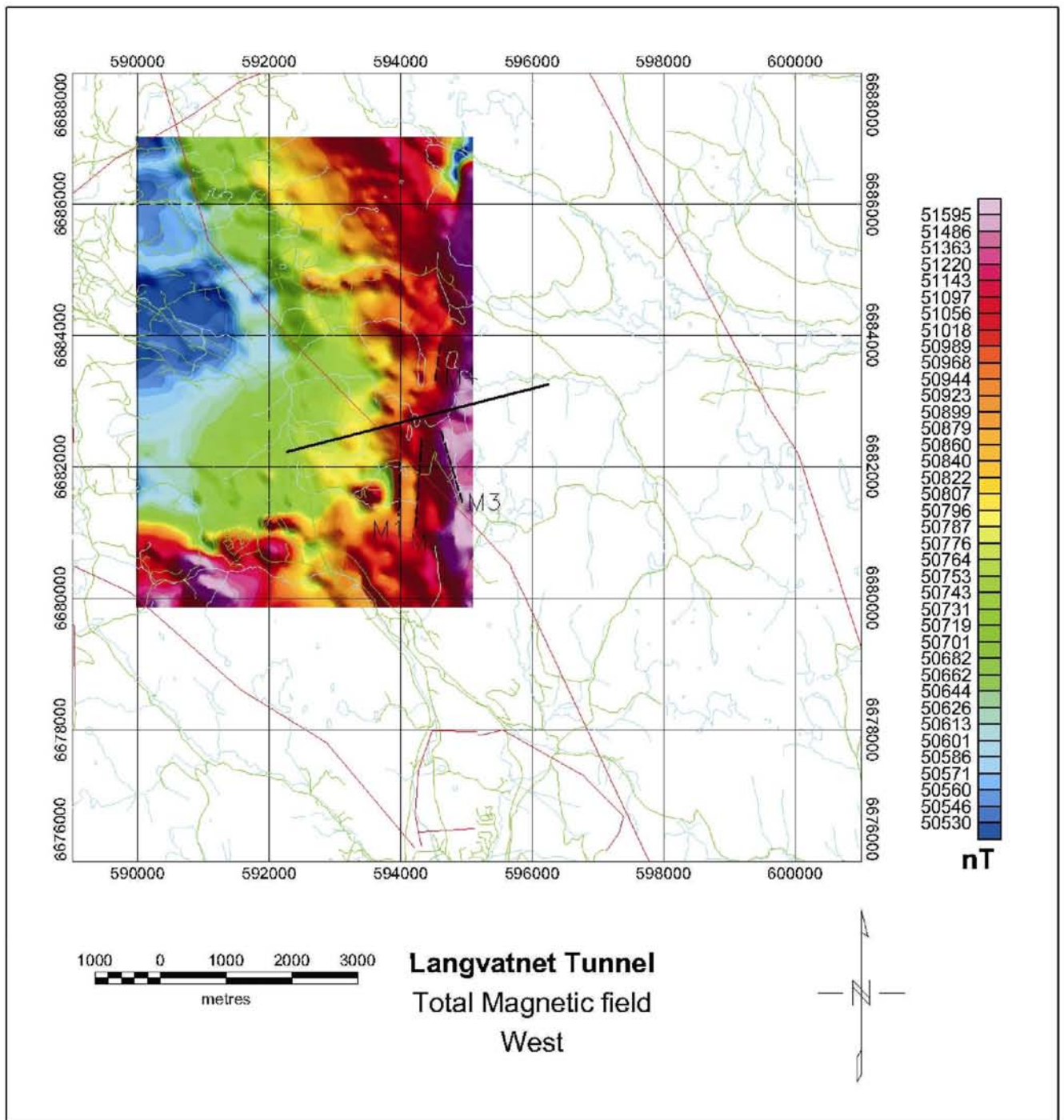


Fig. A1. Total magnetic field lineament anomalies from Hamar survey.

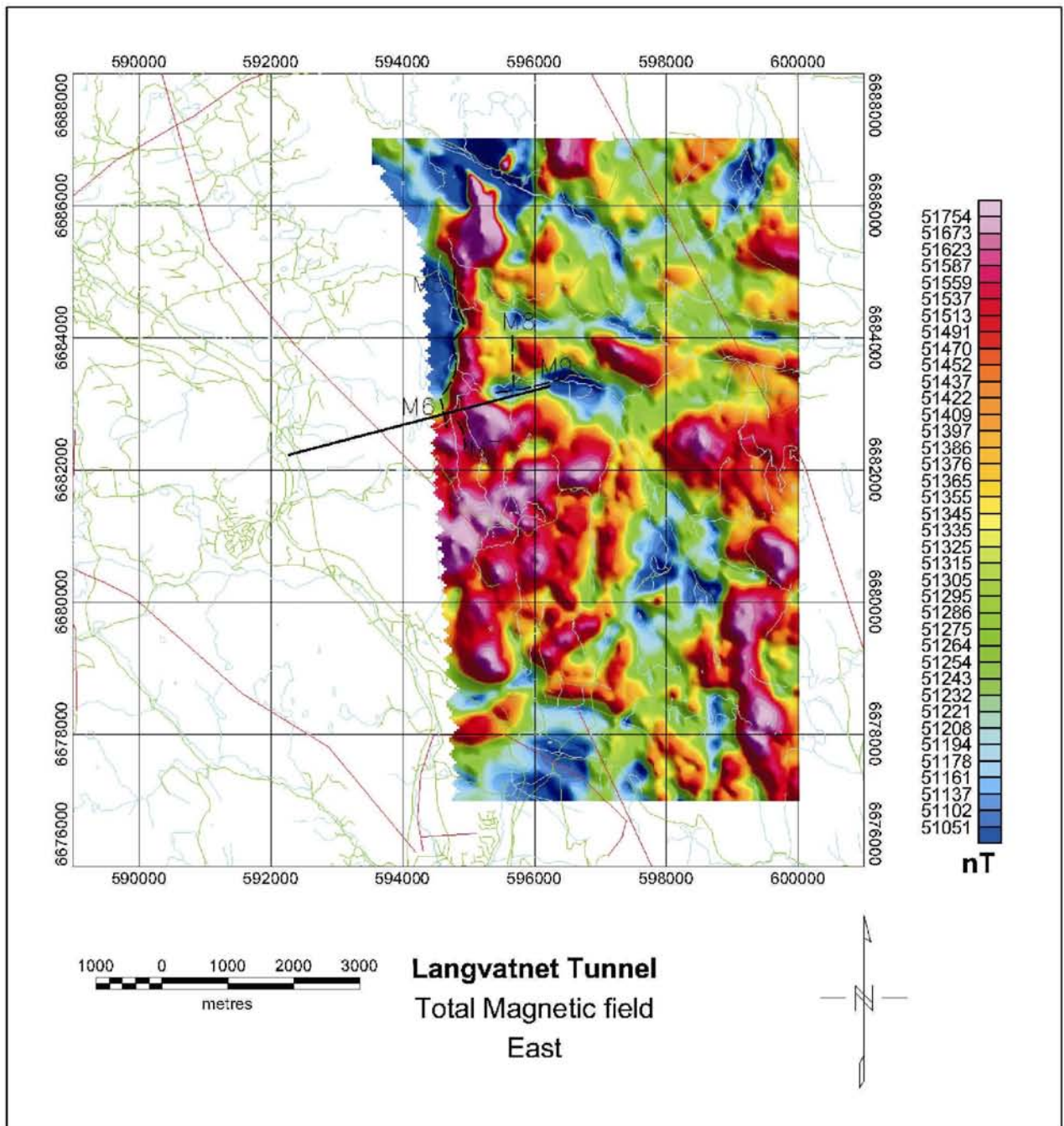


Fig. A2. Total magnetic field lineament anomalies from Hurdal survey.

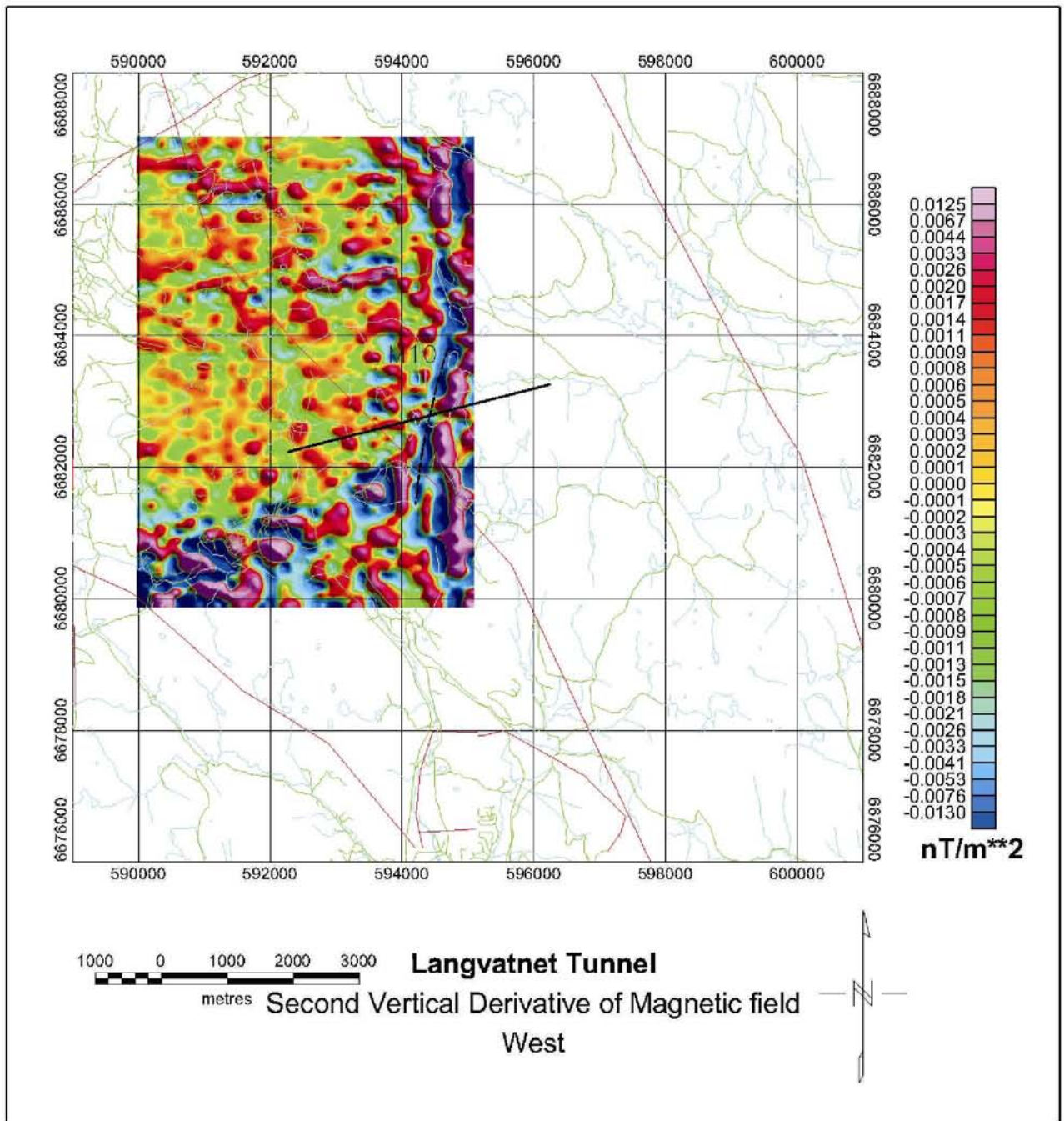


Fig. A3. Second vertical derivative of total magnetic field lineament anomalies from Gran survey.

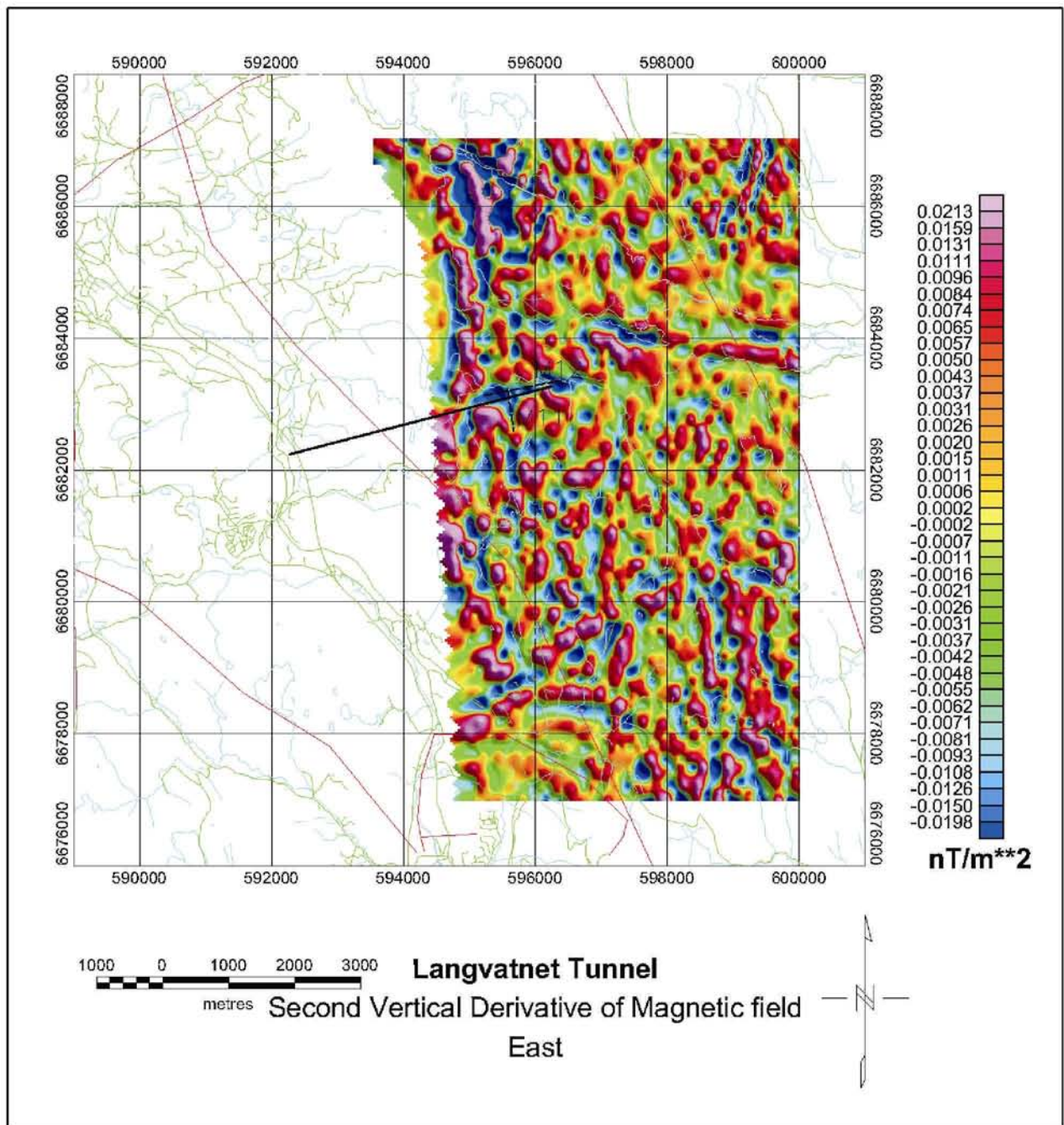


Fig. A4. Second vertical derivative of total magnetic field lineament anomalies from Hurdal survey.

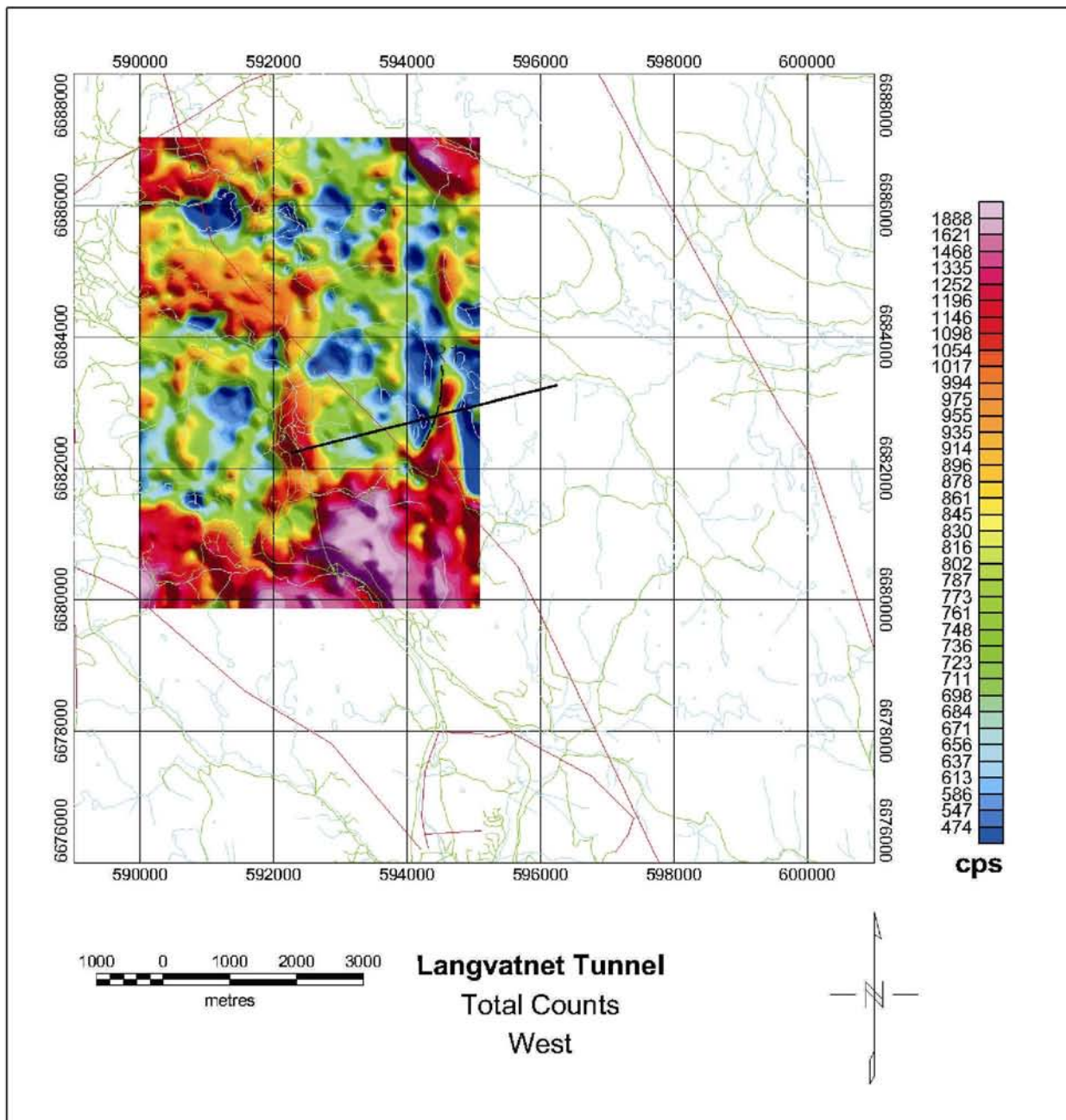


Fig. A5. Total count lineament anomalies from Gran survey.

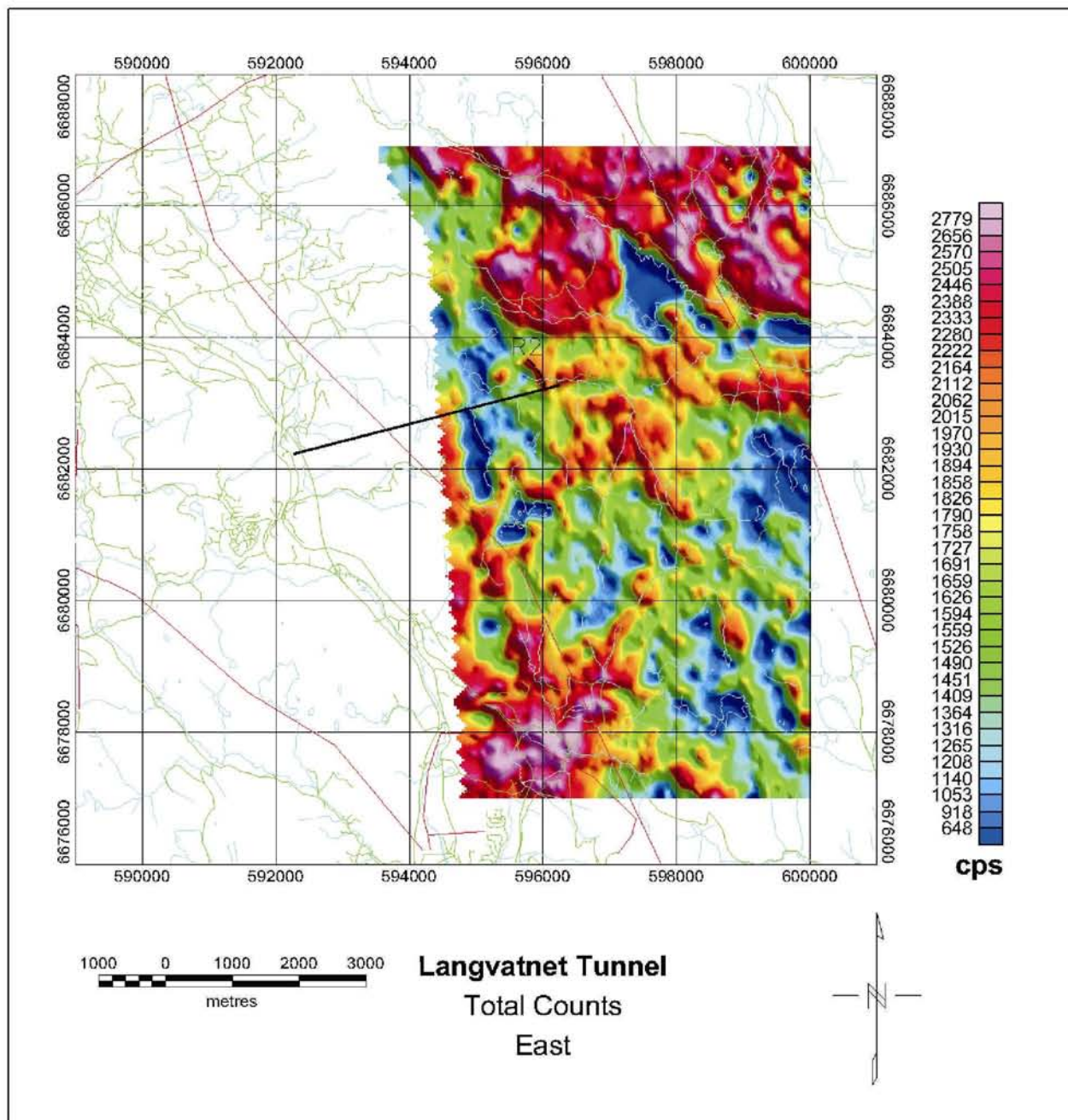


Fig. A6. Total count lineament anomalies from Hurdal survey.

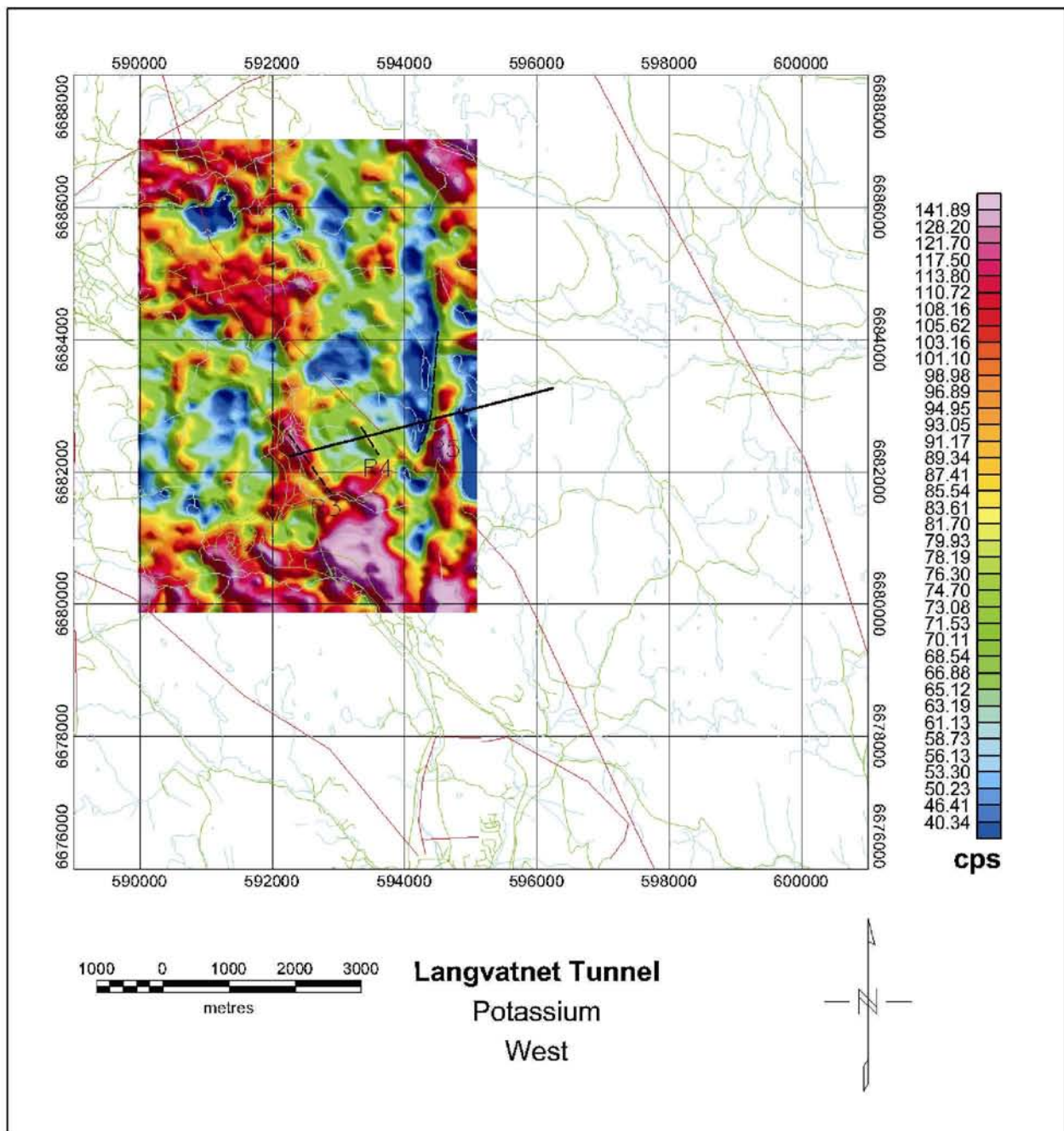


Fig. A7. Potassium lineament anomalies from Gran survey.

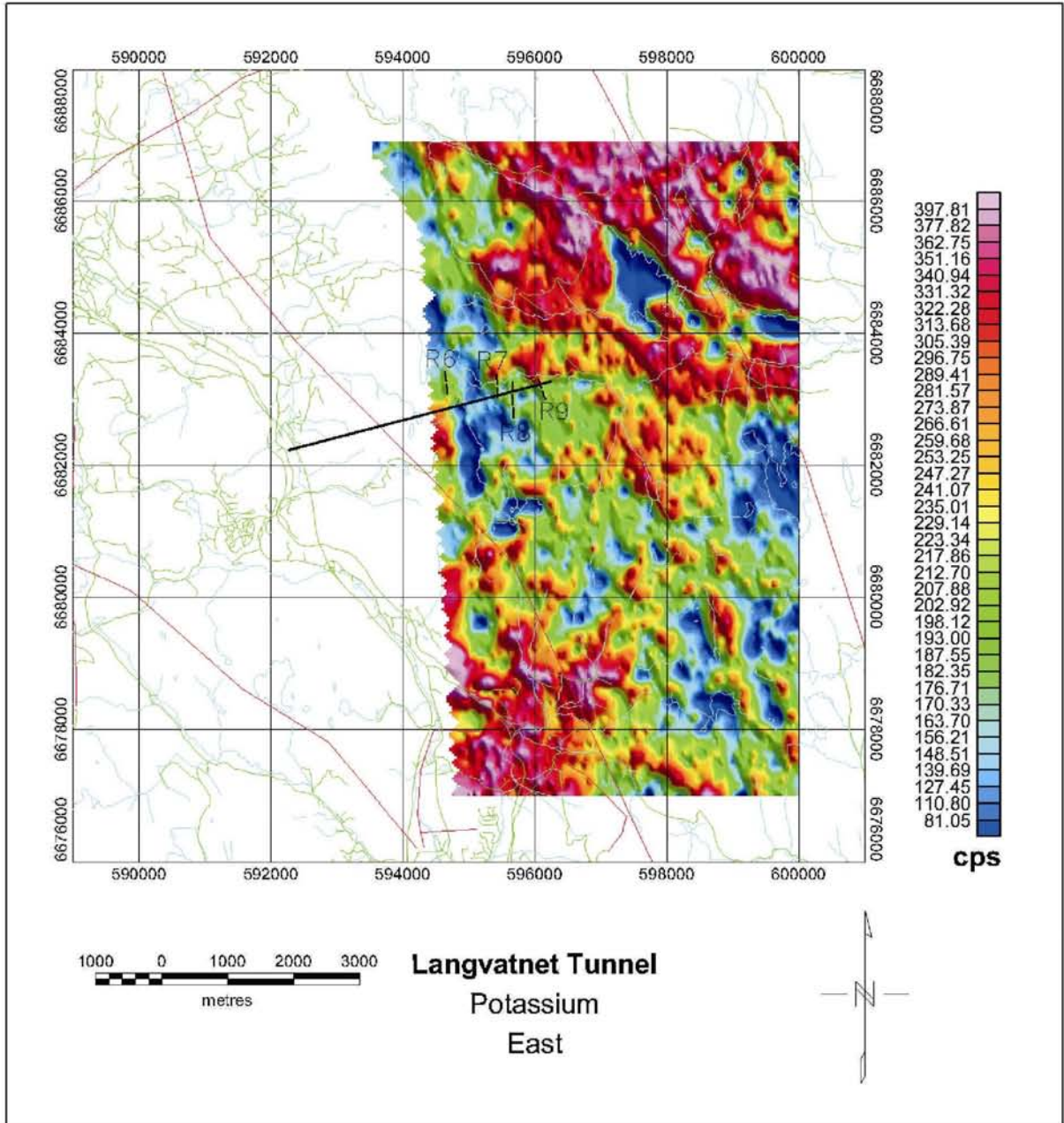


Fig. A8. Potassium lineament anomalies from Hurdal survey.

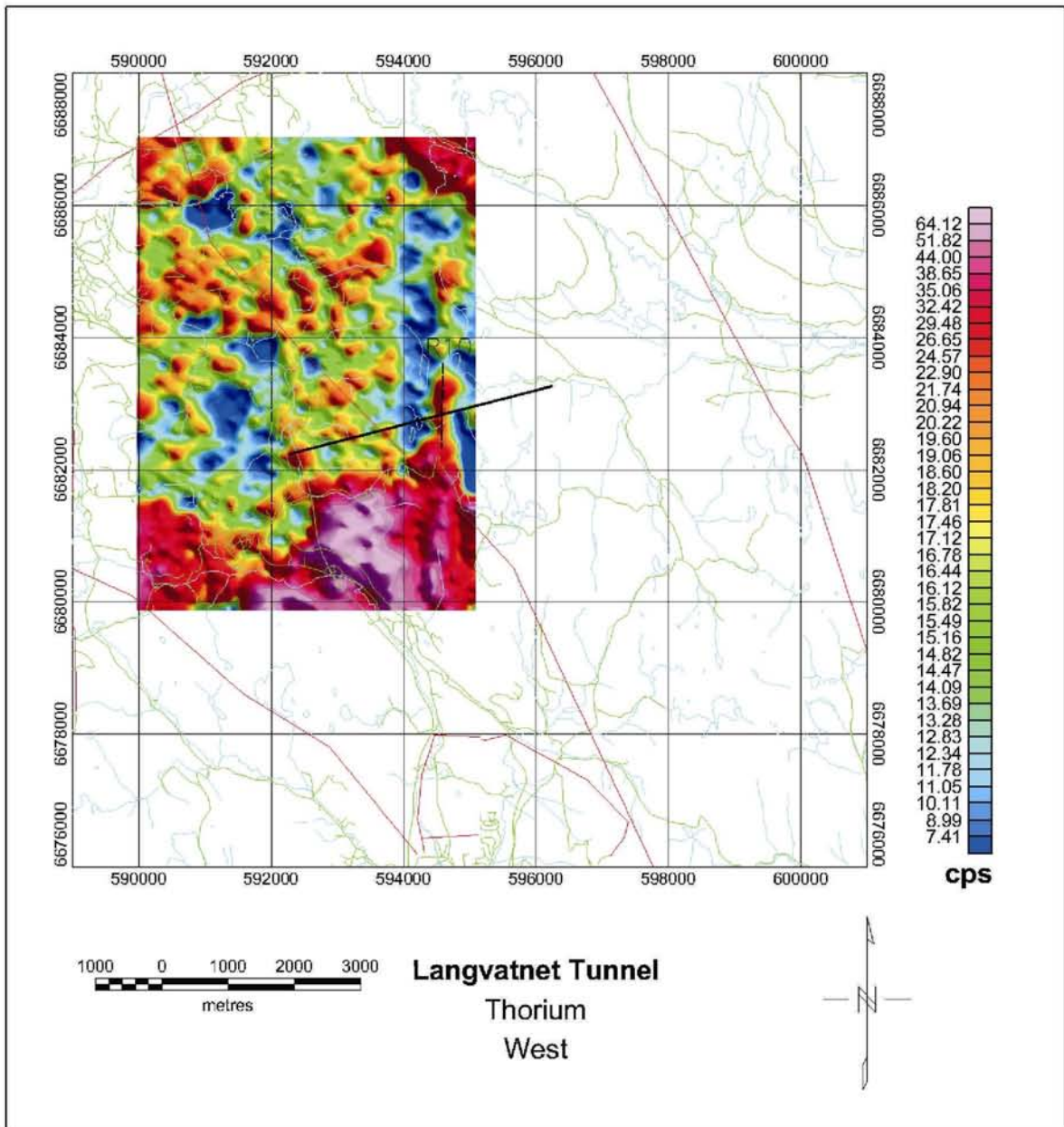


Fig. A9. Thorium lineament anomalies from Gran survey.

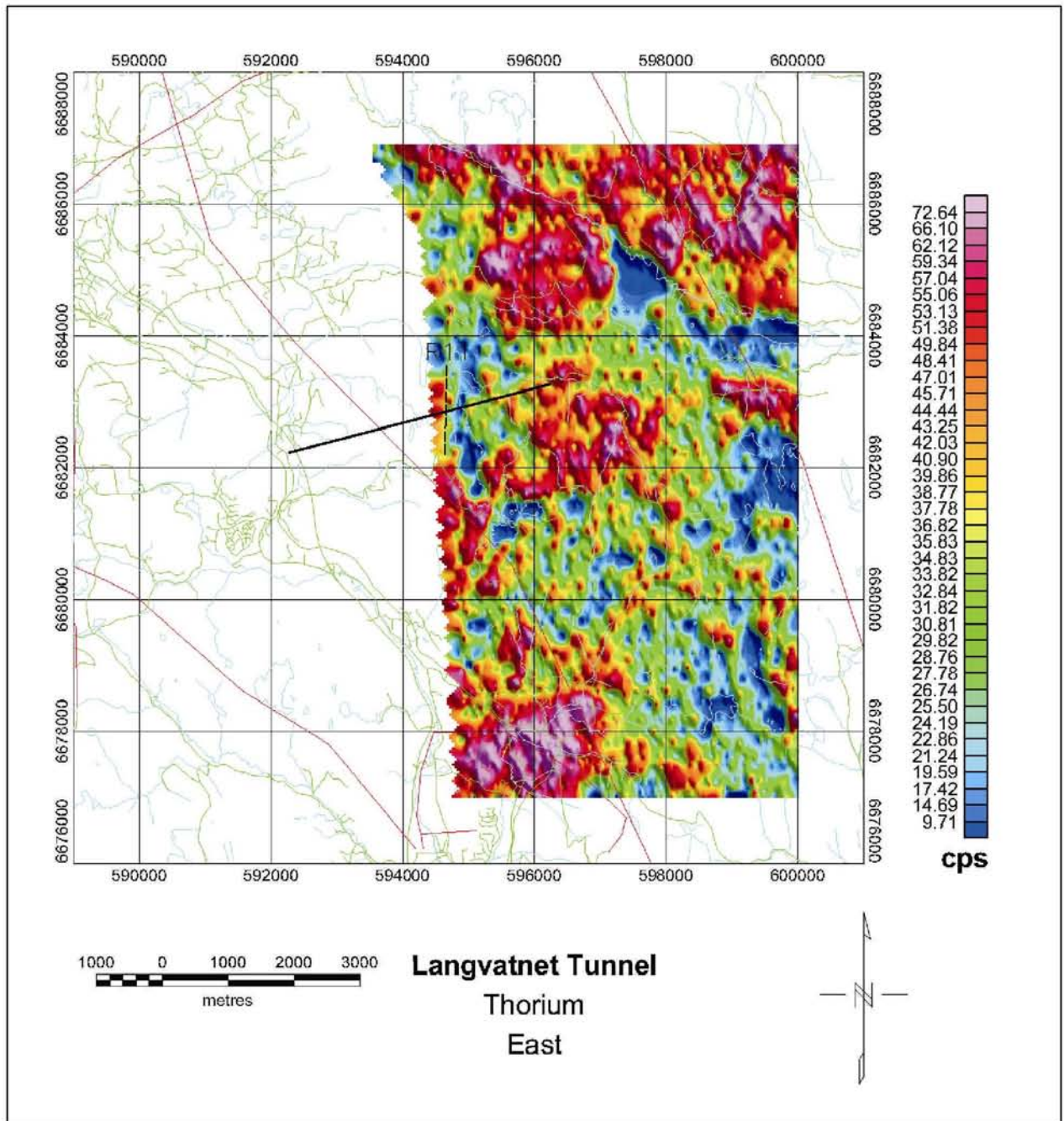


Fig. A10. Thorium lineament anomalies from Hurdal survey.

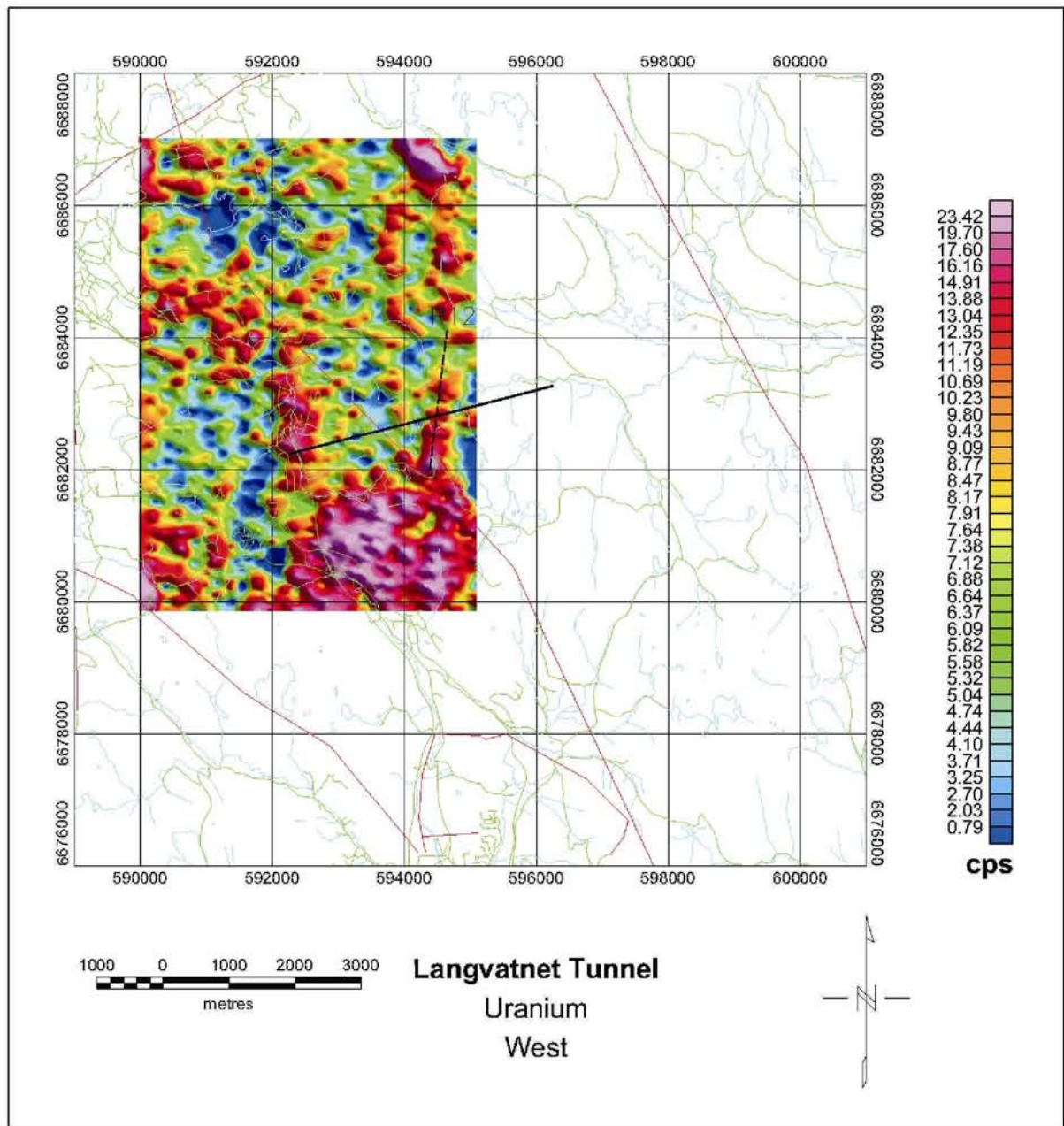


Fig. A11. Uranium lineament anomalies from Gran survey.

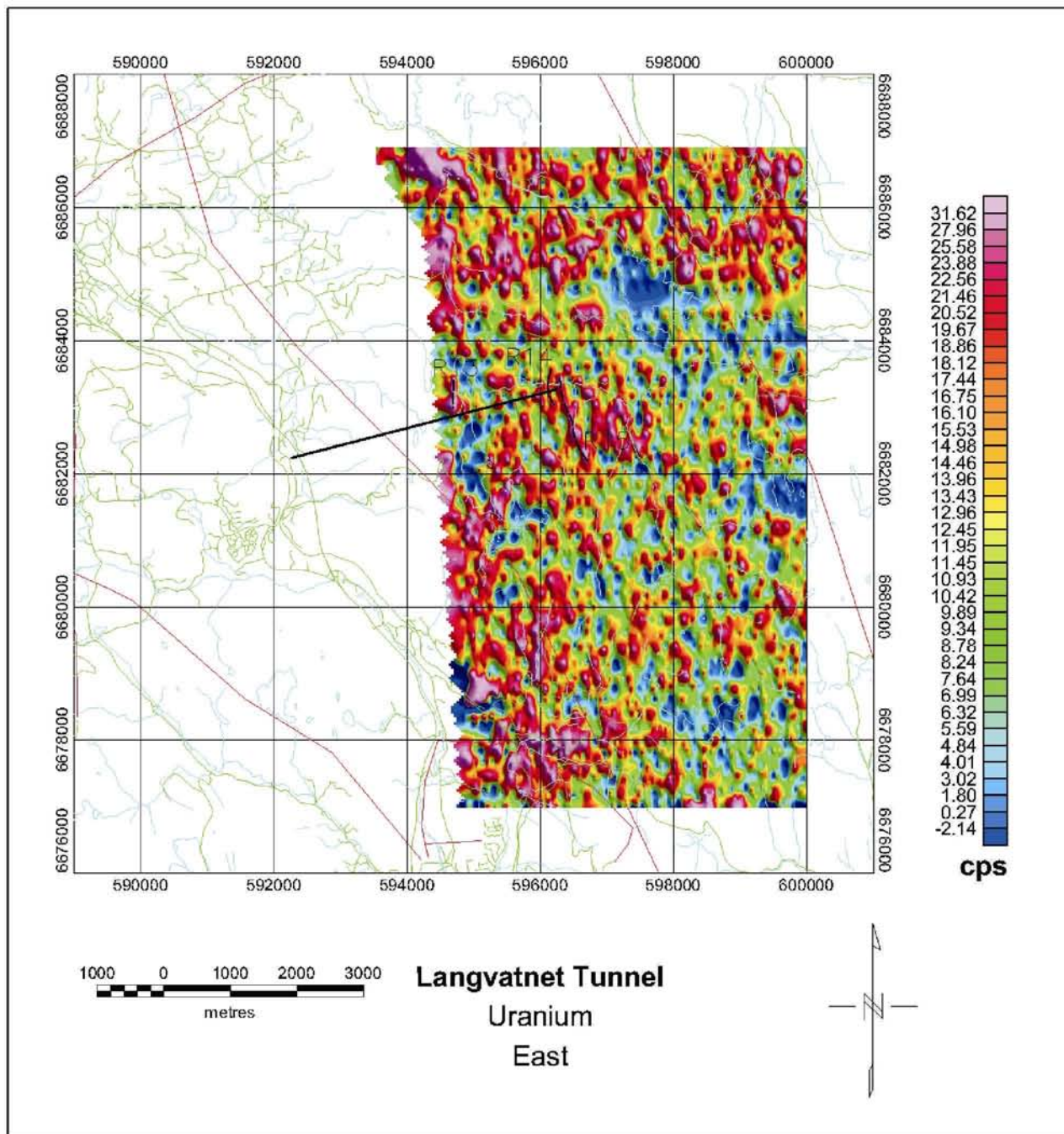


Fig. A12. Uranium lineament anomalies from Hurdal survey.

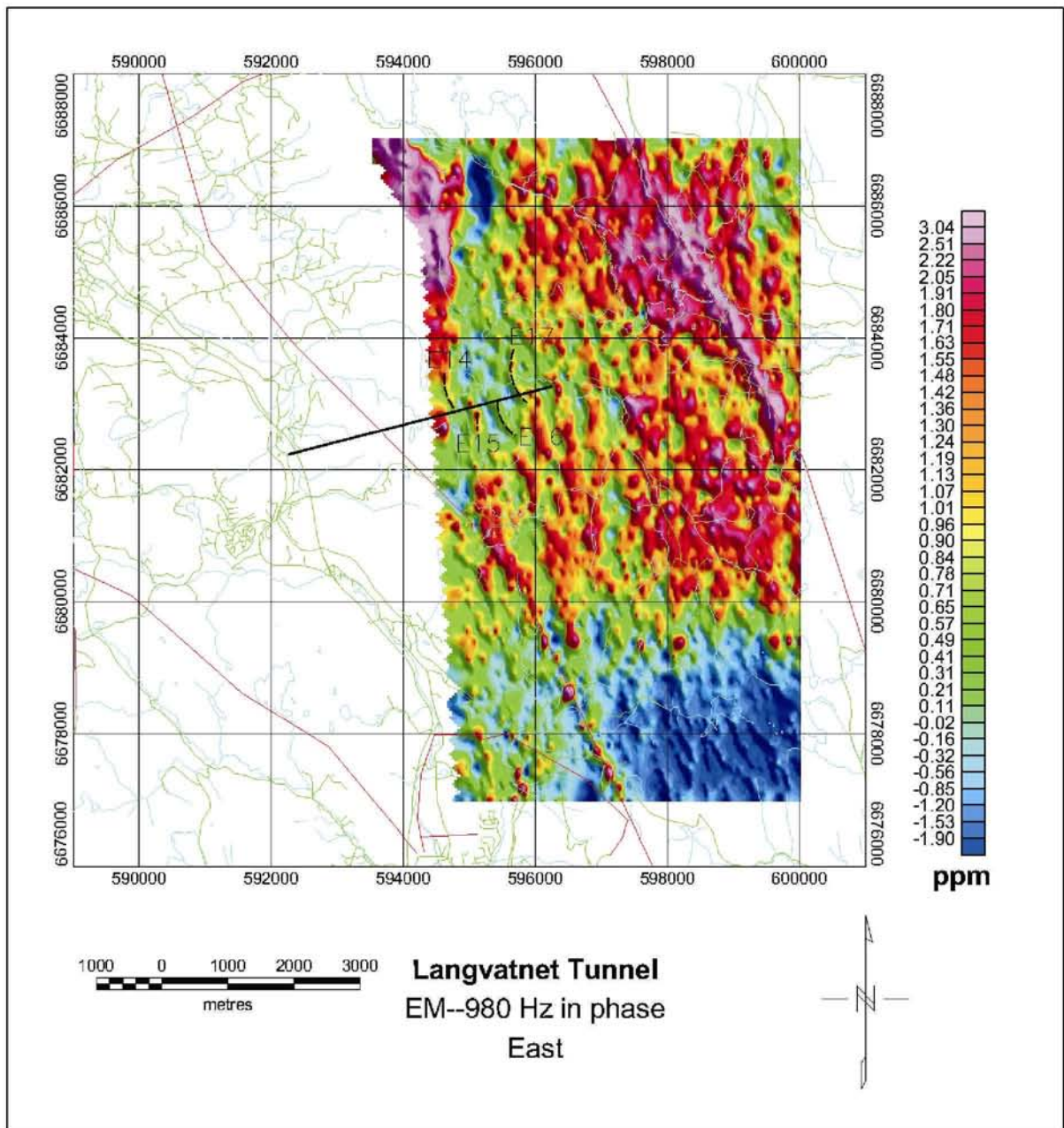


Fig. A13. EM lineament anomalies from Hurdal survey, 980 Hz VCA in phase response.

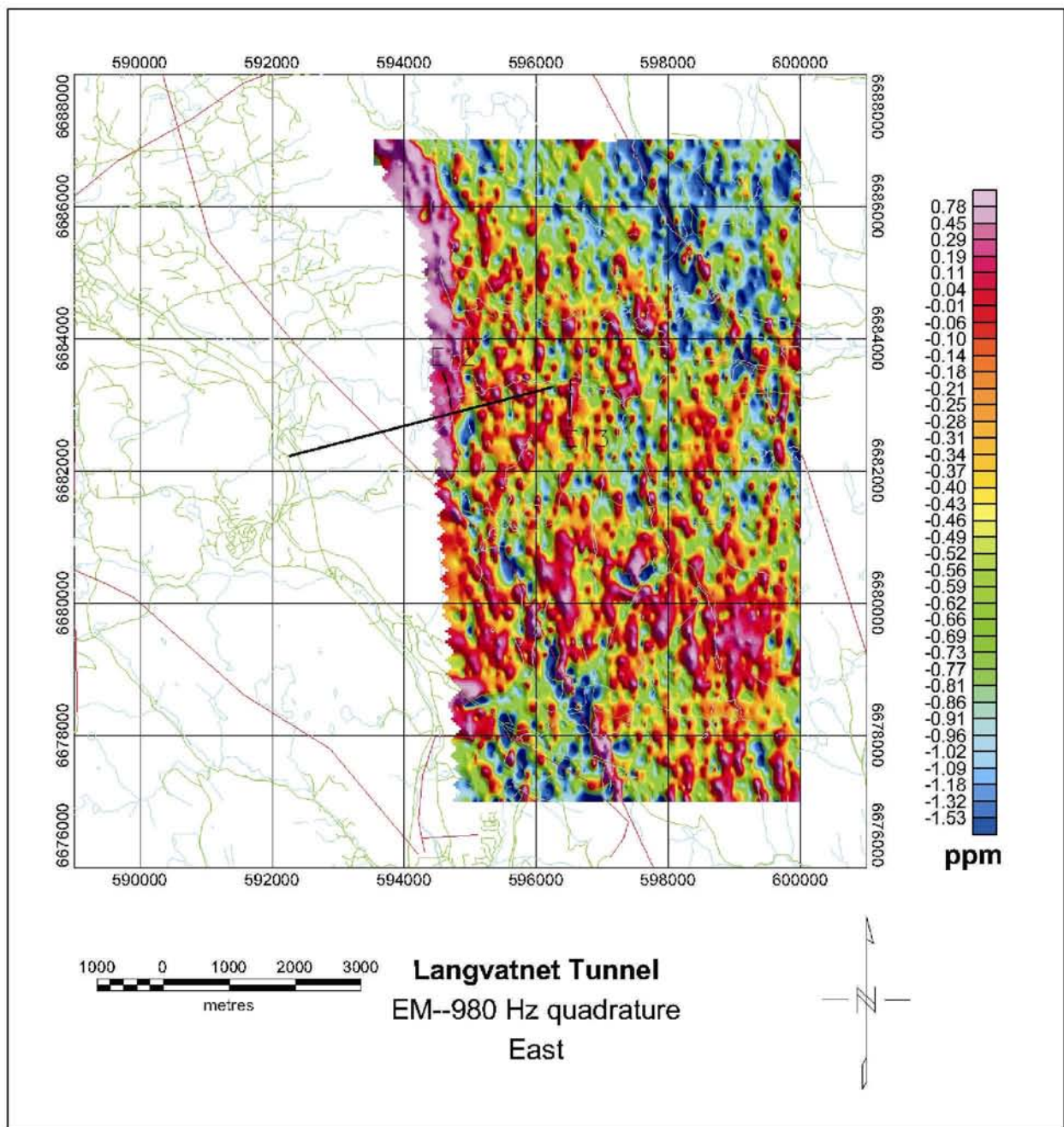


Fig. A14. EM lineament anomalies from Hurdal survey, 980 Hz VCA quadrature response.

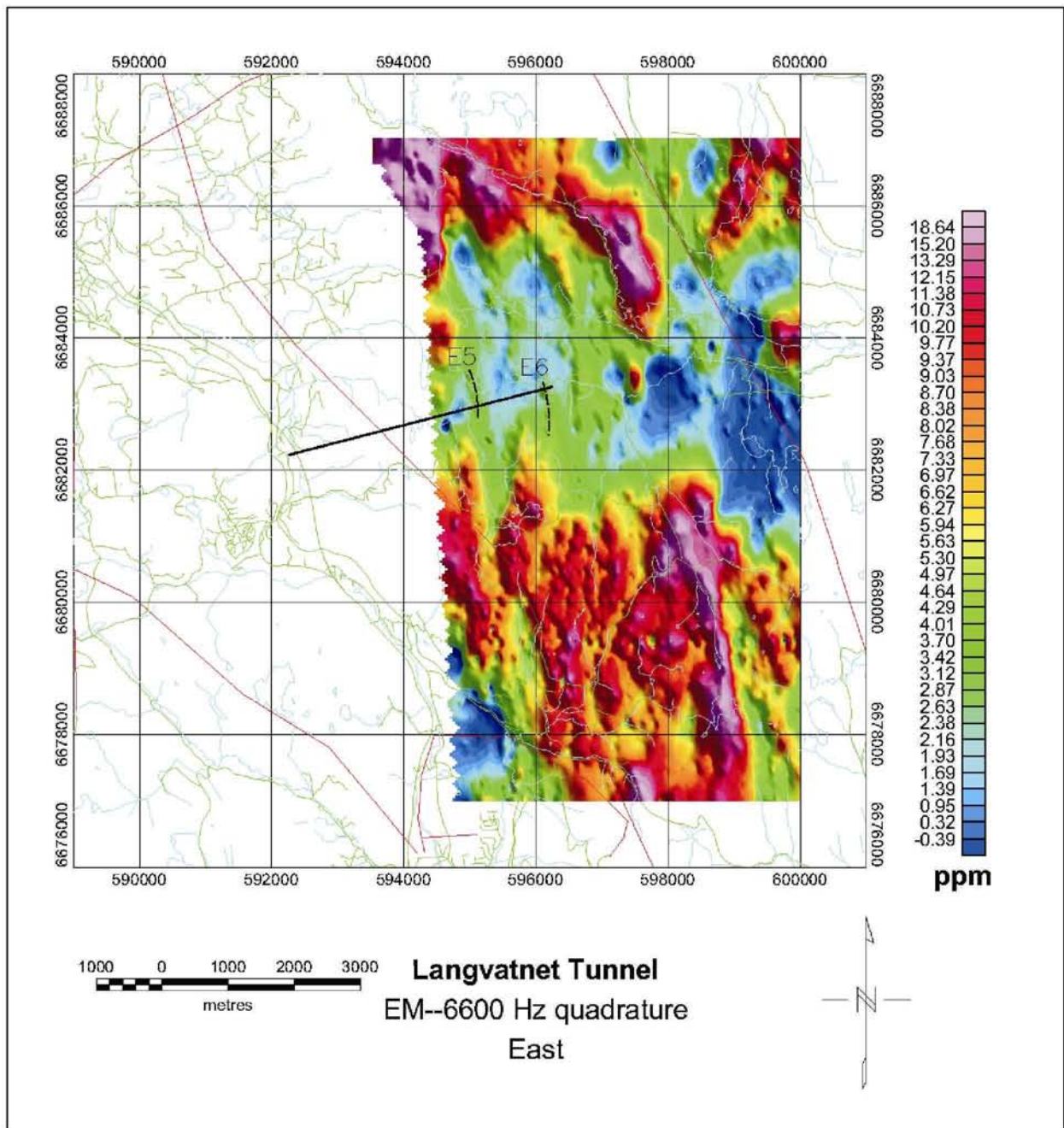


Fig. A15. EM lineament anomalies from Hurdal survey, 6600 Hz HCP quadrature response.

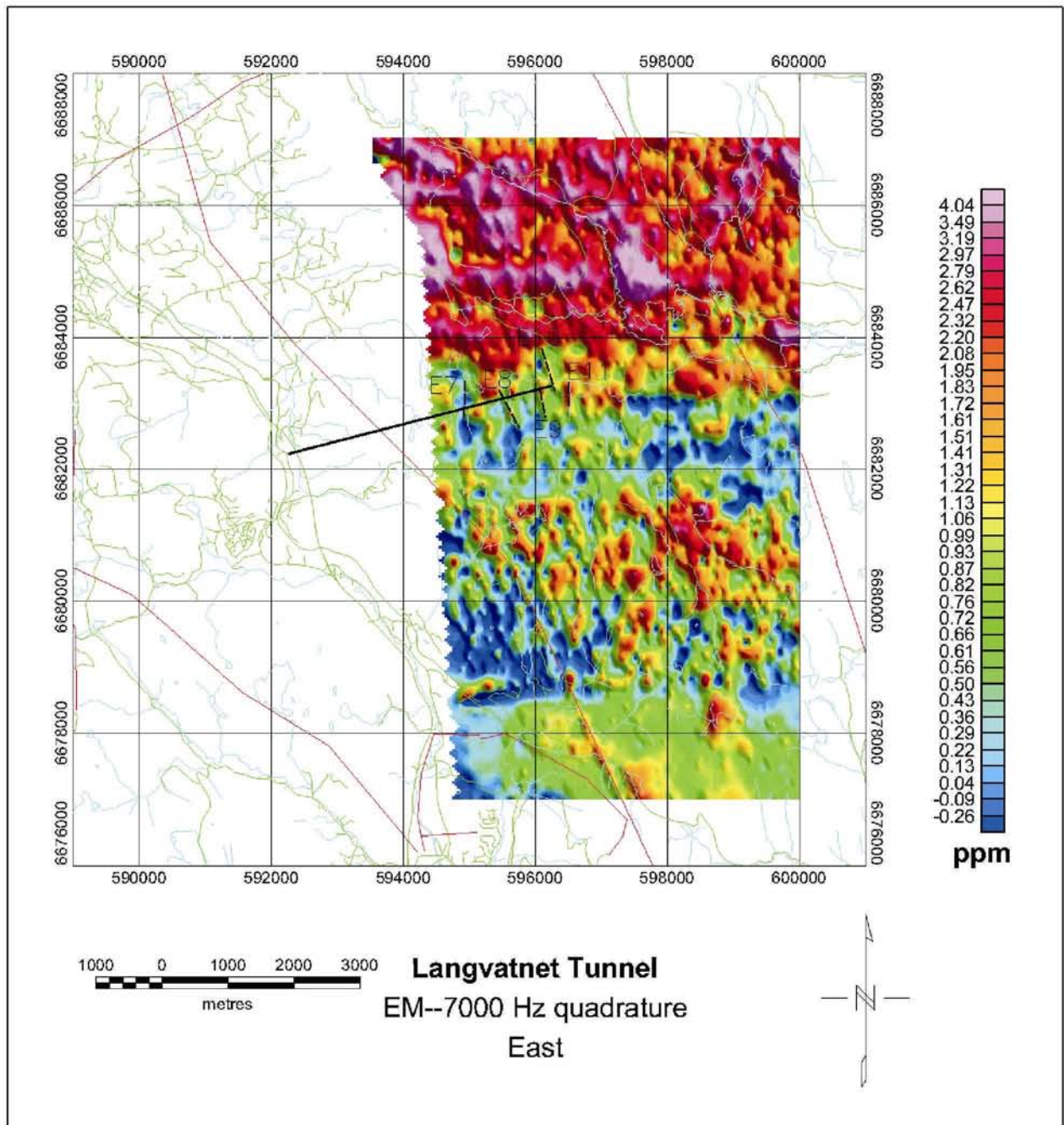


Fig. A16. EM lineament anomalies from Hurdal survey, 7000 Hz VCA quadrature response.

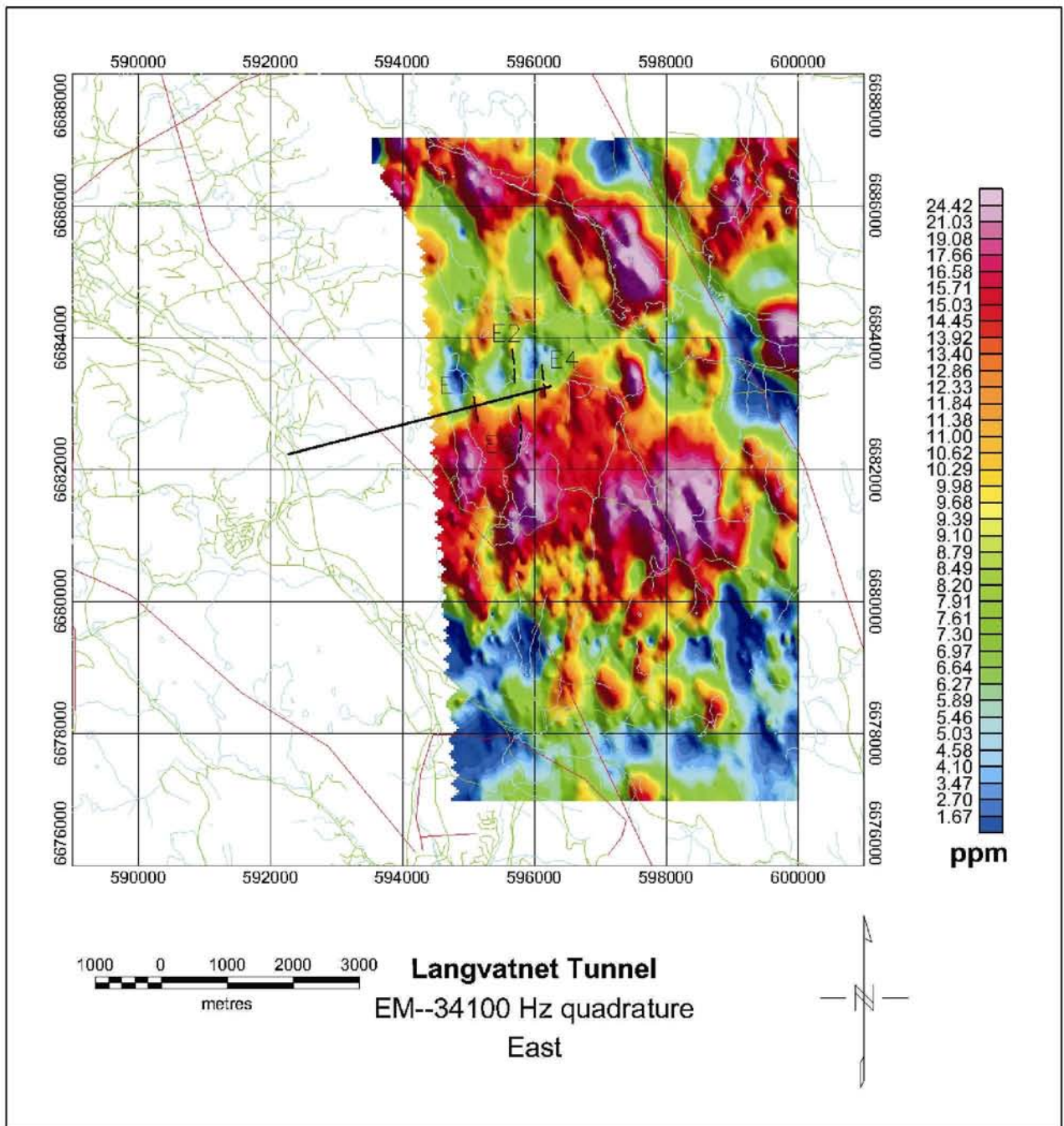


Fig. A17. EM lineament anomalies from Hurdal survey, 34100 Hz HCP quadrature response.

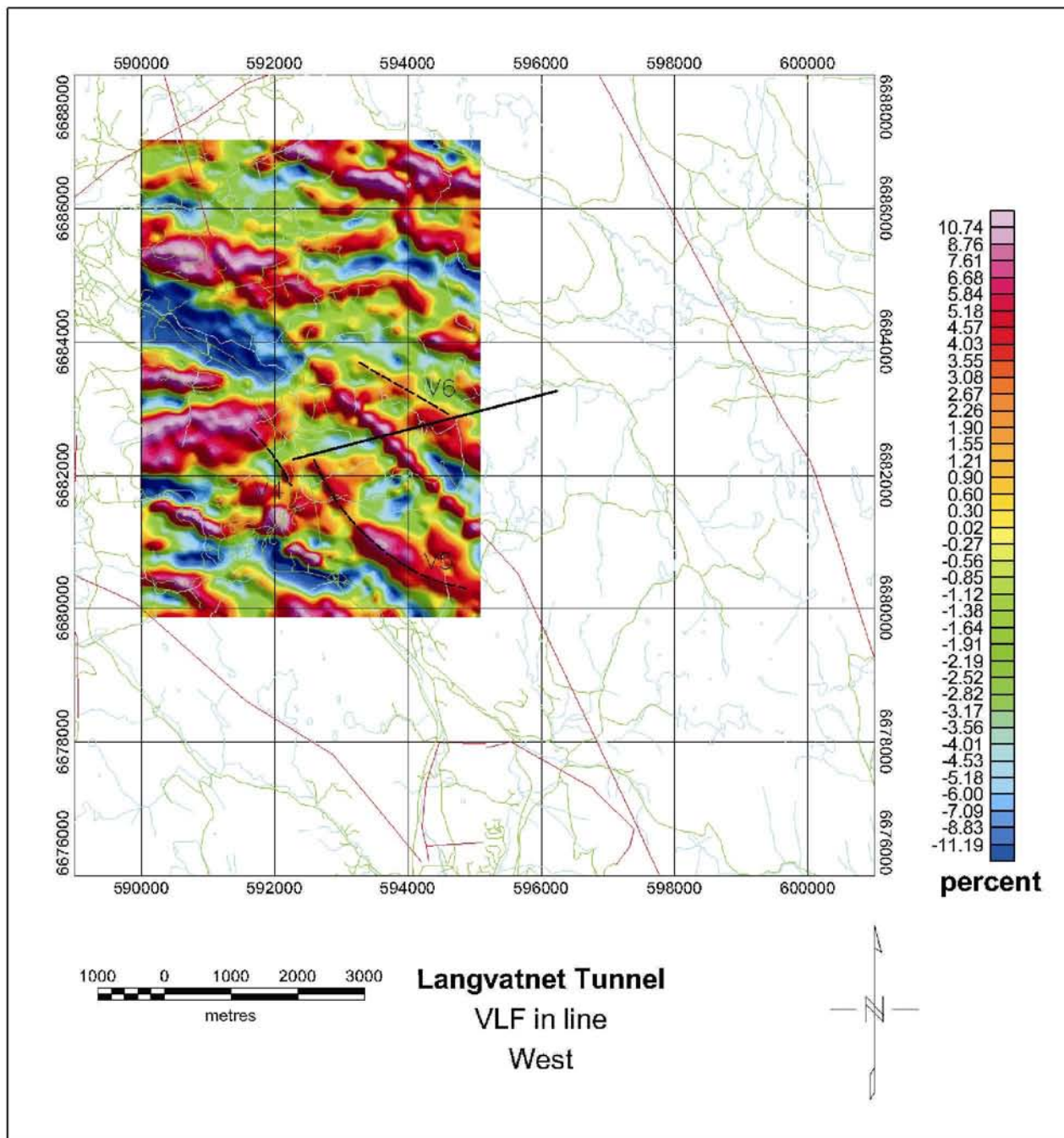


Fig. A18. VLF lineament anomalies from Gran survey, in line receiver.

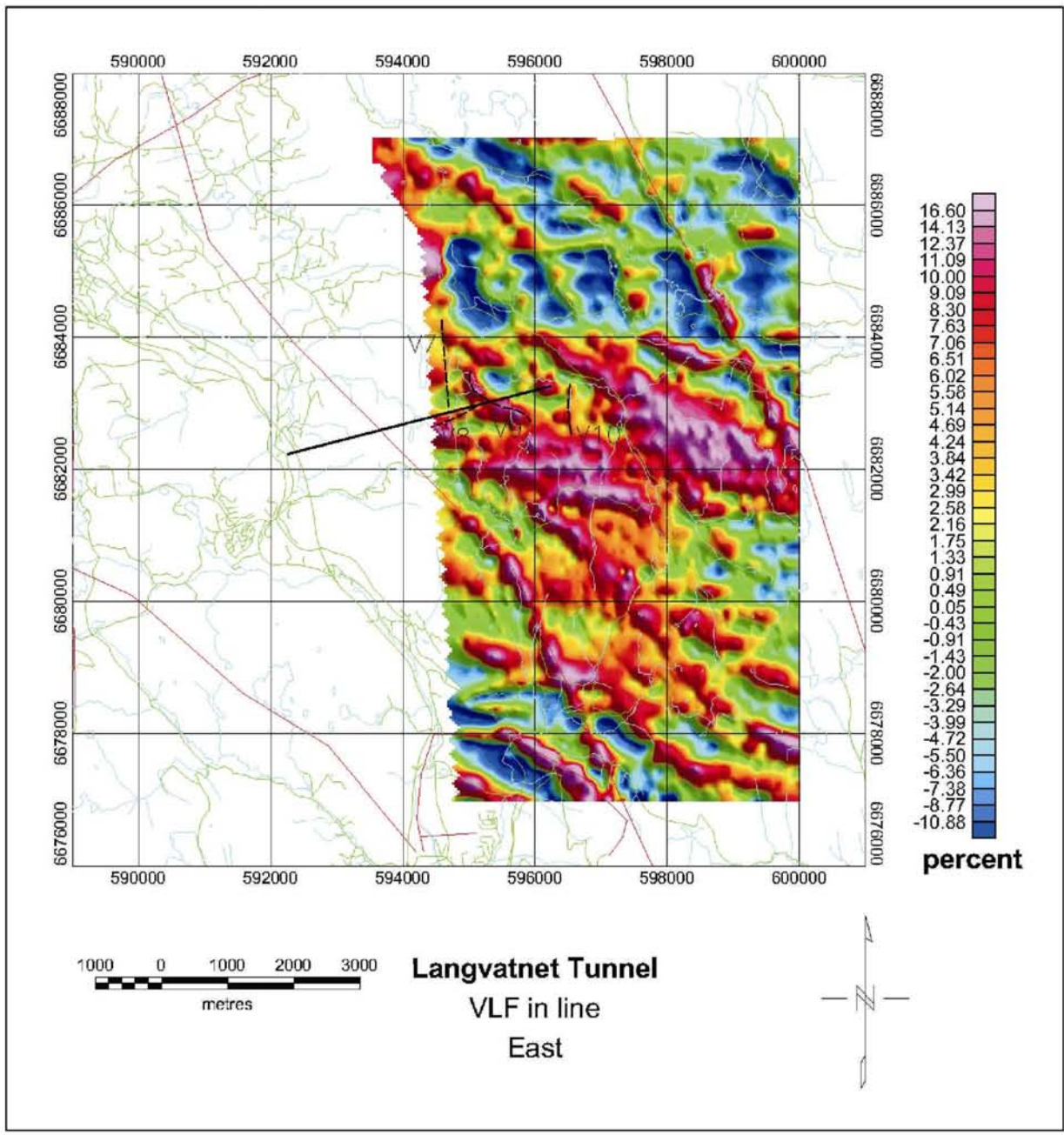


Fig. A19. VLF lineament anomalies from Hurdal survey, in line receiver.

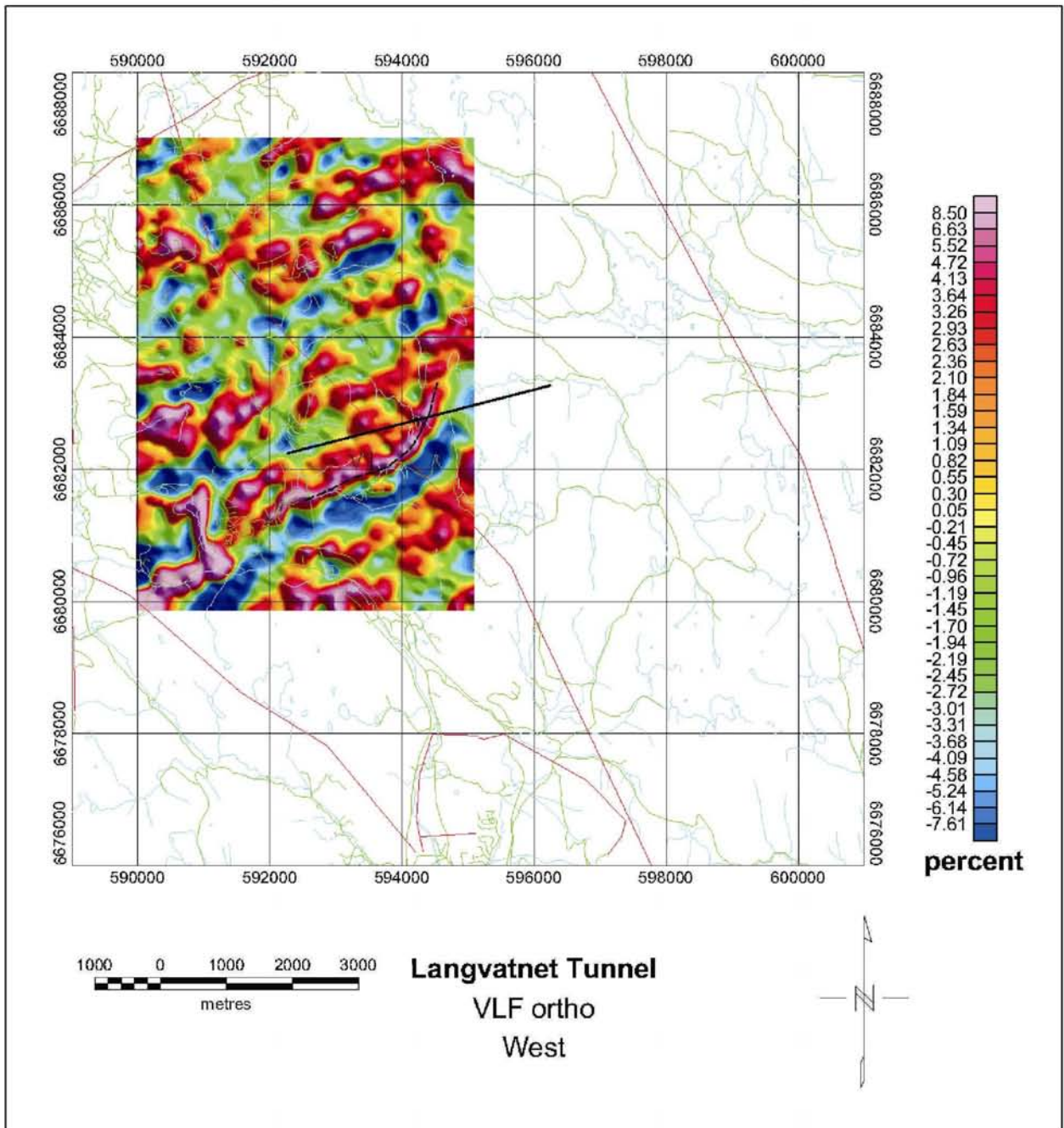


Fig. A20. VLF lineament anomalies from Gran survey, orthogonal receiver.

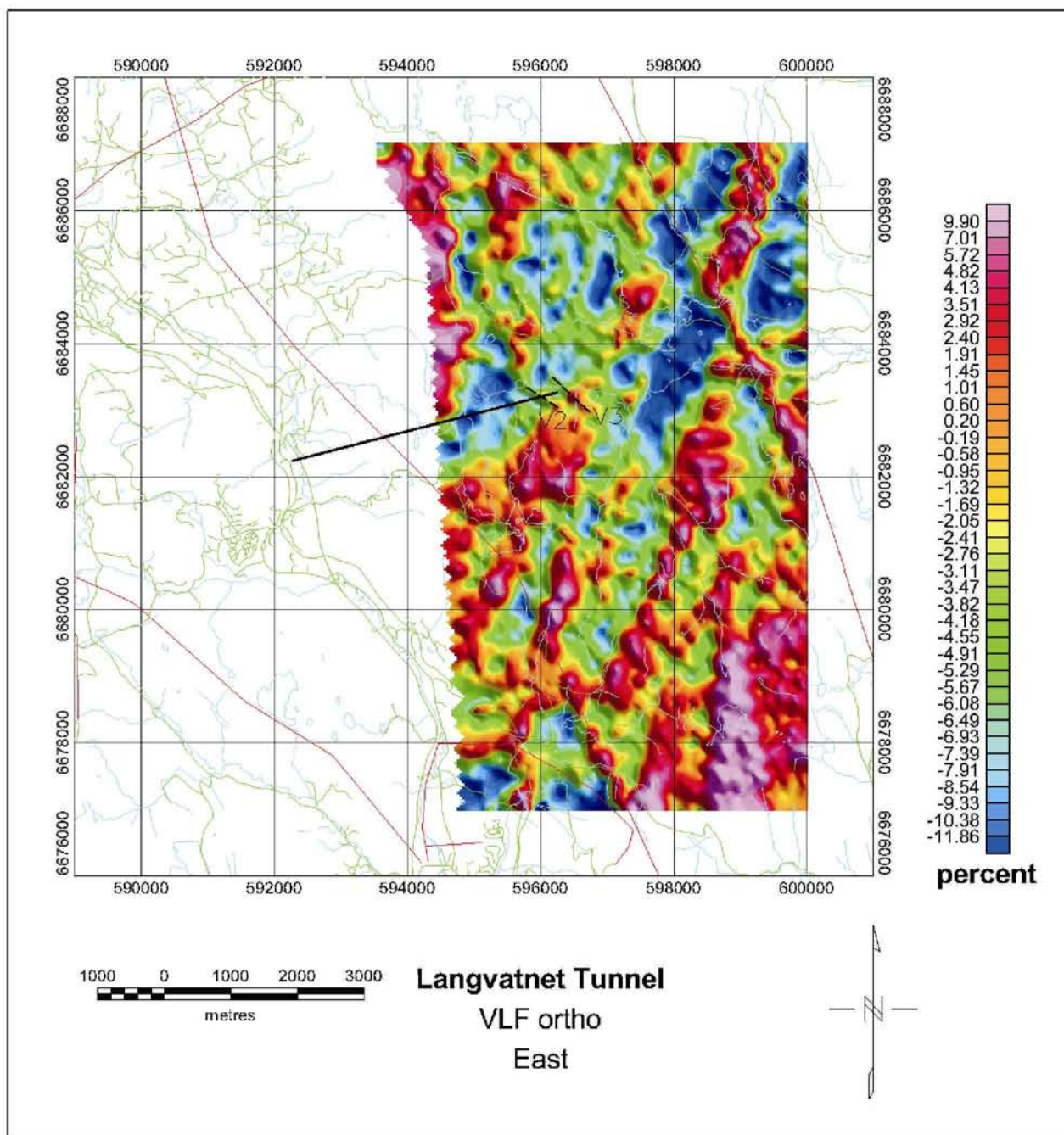


Fig. A21. VLF lineament anomalies from Hurdal survey, orthogonal receiver.

Anomaly key:

- Magnetic anomaly
- Conductive EM anomaly
- Resistive EM anomaly
- VLF anomaly
- Radiometric anomaly

Surface features key:

- Roads, railways
- Lakes, rivers, streams
- Power lines

