# Detecting Shallow Geological Features in High Resolution Aeromagnetic Data of the Horn River Basin Using Second Derivative in the Gradient Direction (SDGD) and PLUS filters

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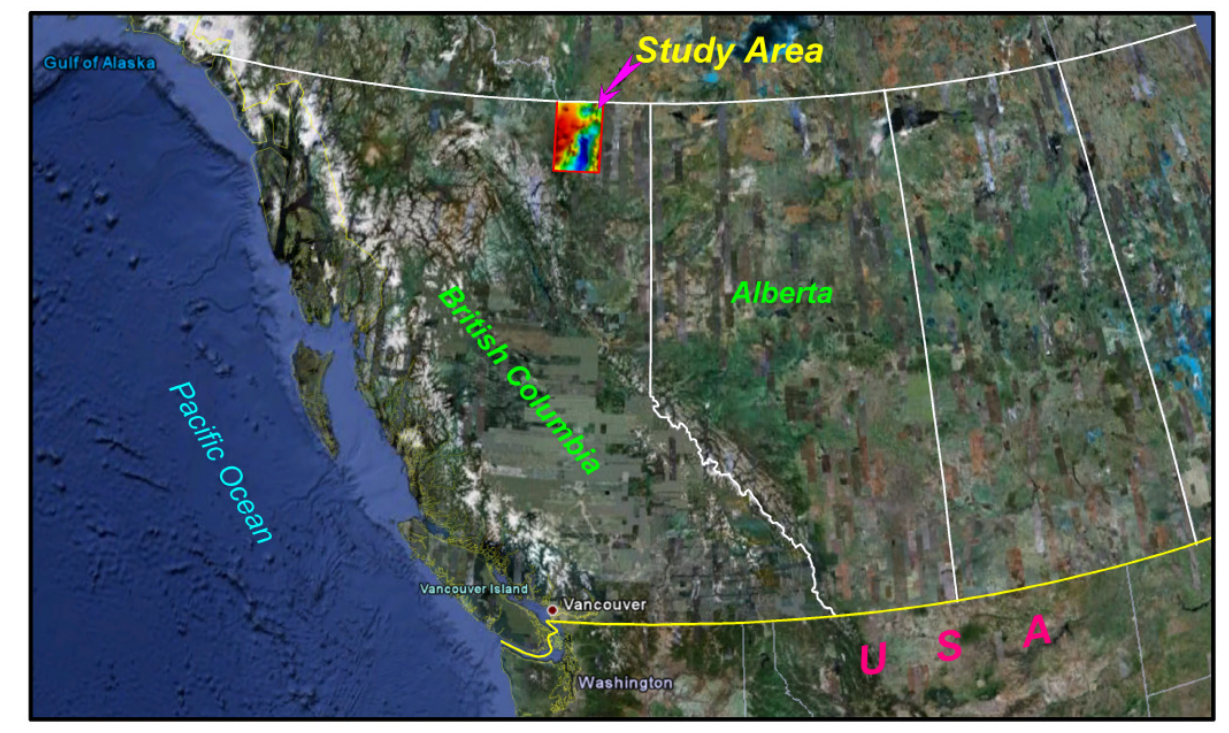
Study Area
Pacific Ocean
Vancouver Island
Vancouver
Washington
U S A

Figure 1. Location of the study area.

## Summary

Detecting shallow geological features such as faults, fractures and buried channels is very important for oil and gas exploration. These shallow geological features also play an important role in geohazards detection. One way to detect shallow geological features is by mapping the short-wavelength high-frequency components of **H**igh **R**esolution **A**ero**M**agnetic (HRAM) data. The short-wavelength high-frequency components of HRAM data are normally attributed to shallow geological features. Several spatial and frequency based filters exist to detect shallow geological features in HRAM data. Among these filters are the derivative, gradient and the more recently introduced tilt angle. Although, these filters provide a way to detect shallow geological features in HRAM data, they amplify the level of noise and produce artifacts in the data especially if the data are processed in the frequency domain.

In this poster we introduce a group of filters to process HRAM data. These filters aim at enhancing the high-frequency contents of HRAM data and reducing the level of noise and thus revealing shallow geological features related to buried channels, faults and fractures more clearly. These filters are known as the second derivative in the gradient direction (SDGD), the Laplace and the PLUS. These filters were applied on HRAM data covering the Horn River Basin in Northeast British Columbia (NEBC). The primary goal of this project is to demonstrate the utility of HRAM data in mapping shallow geological features in the shale gas area of Horn River Basin. Prior to applying the Laplace, the SDGD and the PLUS filters, the HRAM image was convolved with a Gaussian filter in order to reduce noise in the data. The preliminary results of this study are very positive. We were able to detect features attributable to buried channels, faults and fractures that we were not able to detect on images produced by using traditional filters.

## Introduction

Shallow geological features such as buried channels, faults and fractures are becoming important elements in oil and gas exploration as well as in geohazard detection. Several types of digital filters exist to detect shallow geological features. Most of these filters utilize the short-wavelength high-frequency components of HRAM data that are associated with shallow geological features. Although these filters are good at enhancing shallow geological features, they frequently enhance the level of noise and introduce artifacts in the data. In this poster we tested three gradient-based filters that might be able to tackle these problems. These filters are known as the Laplace, the SDGD and the PLUS.

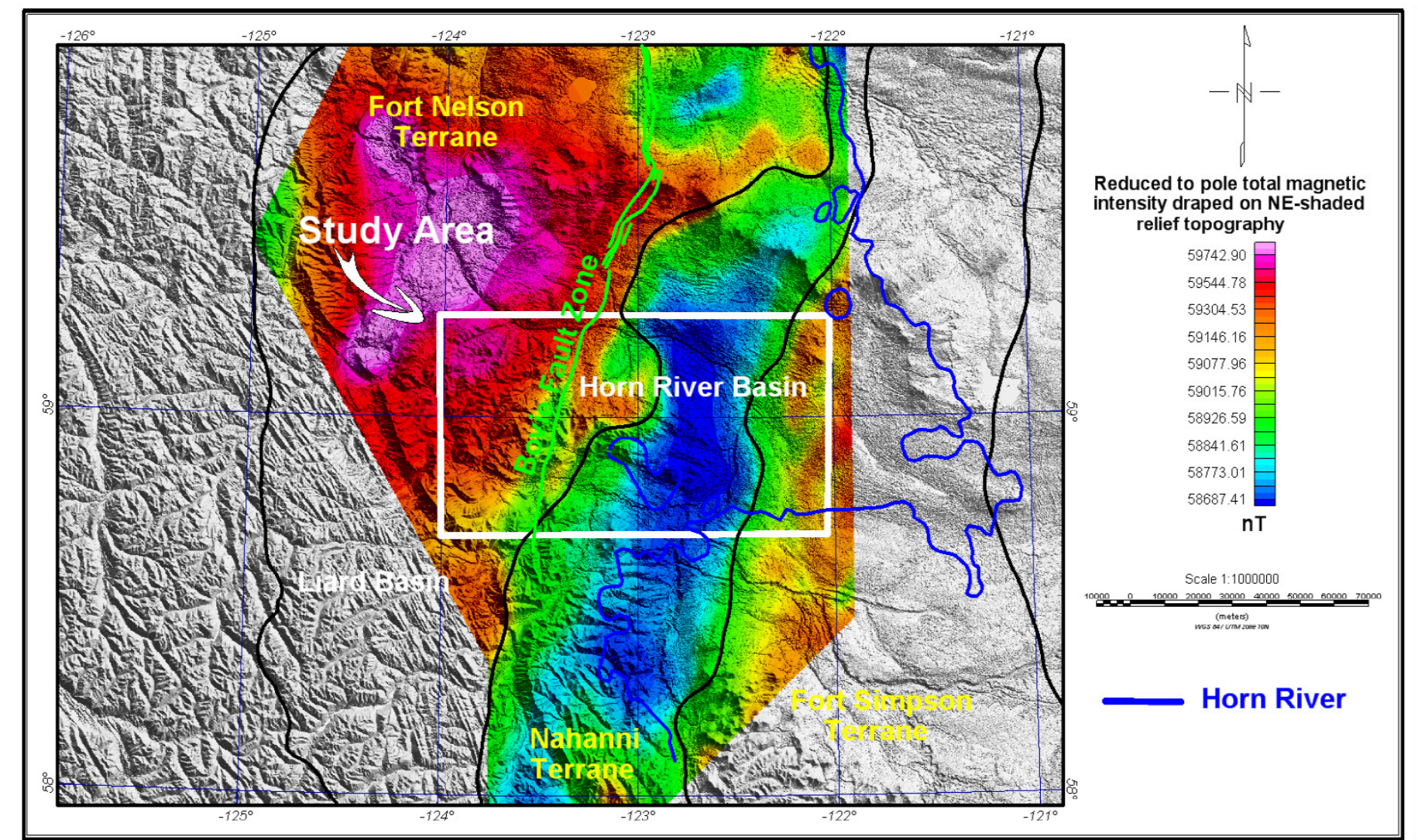
Fort Nelson Terrane
Study Area
Horn River Basin
Bovie Fault Zone
Liard Basin
Nahanni Terrane
Fort Simpson Terrane
Reduced to pole total magnetic intensity draped on NE-shaded relief topography
59742.90
59544.78
59304.53
59146.16
59077.96
59015.76
58926.59
58841.61
58773.01
58687.41
nT
Scale 1:1000000
Horn River
-126°
-125°
-124°
-123°
-122°
-121°
59°
58°

Figure 2. Reduced to pole total magnetic intensity of Horn River Basin HRAM data draped on NE-shaded relief topography.

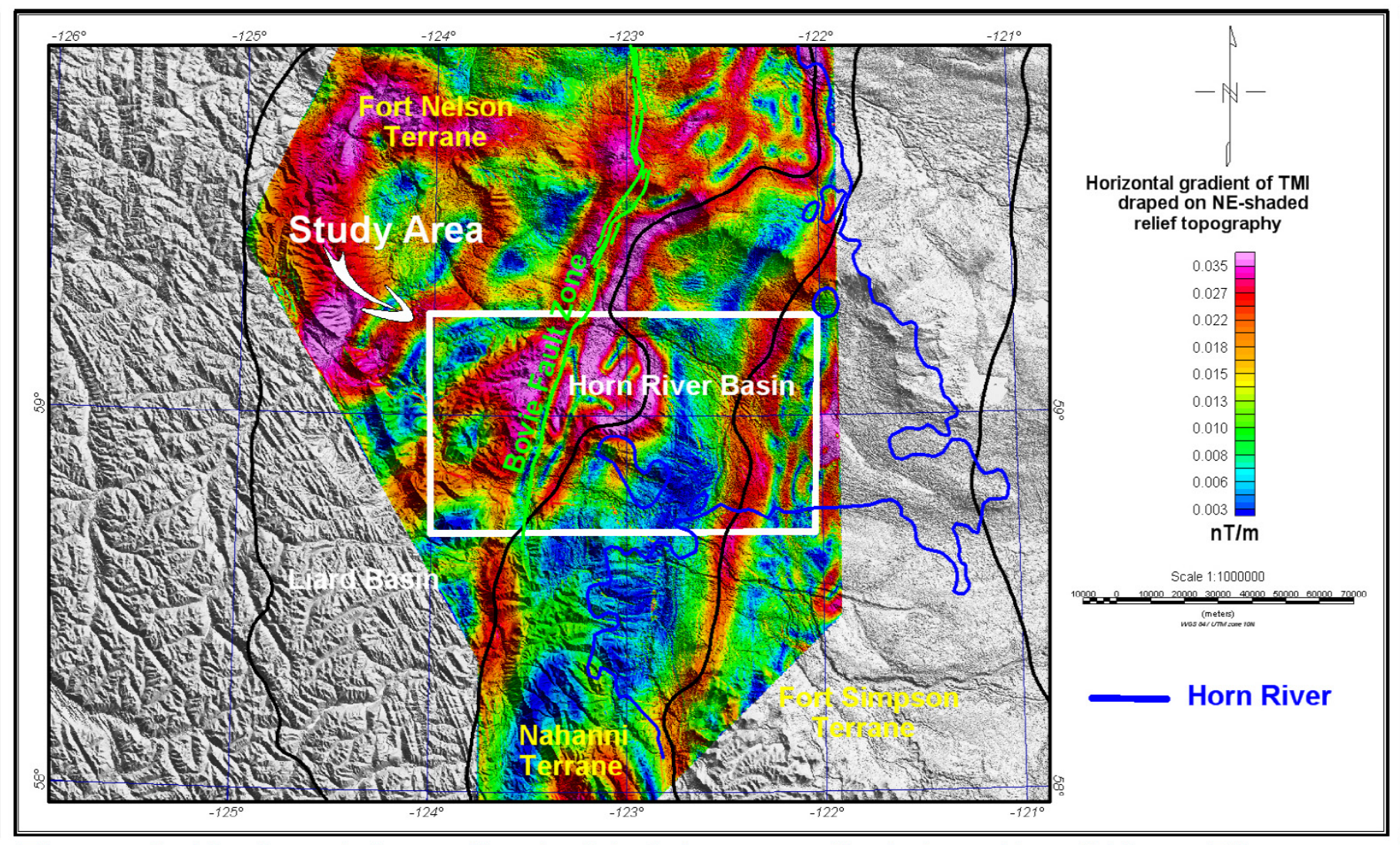
Fort Nelson Terrane
Study Area
Horn River Basin
Bovie Fault Zone
Liard Basin
Nahanni Terrane
Fort Simpson Terrane
Horizontal gradient of TMI draped on NE-shaded relief topography
0.035
0.027
0.022
0.018
0.015
0.013
0.010
0.008
0.006
0.003
nT/m
Scale 1:1000000
Horn River
-126°
-125°
-124°
-123°
-122°
-121°
59°
58°

Figure 3. Horizontal gradient of total magnetic intensity of Horn River Basin HRAM data draped on NE-shaded relief topography.

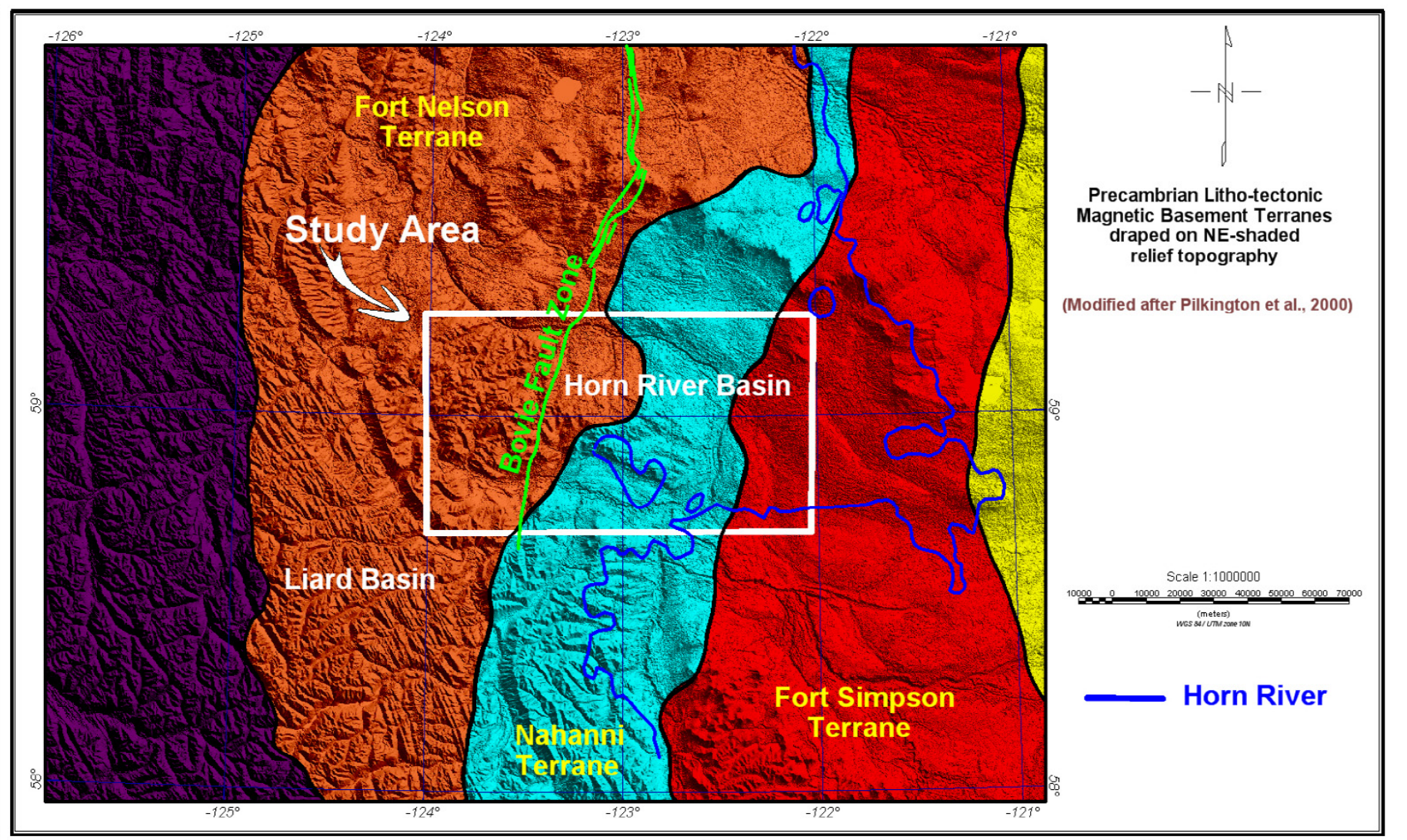
Fort Nelson Terrane
Study Area
Horn River Basin
Bovie Fault Zone
Liard Basin
Nahanni Terrane
Fort Simpson Terrane
Precambrian Litho-tectonic Magnetic Basement Terranes draped on NE-shaded relief topography
(Modified after Pilkington et al., 2000)
Scale 1:1000000
Horn River
-126°
-125°
-124°
-123°
-122°
-121°
59°
58°

Figure 4. Litho-tectonic Precambrian Basement Terranes of Horn River Basin draped on NE-shaded relief topography.

The area selected to test these filters is located in the Horn River Basin of NEBC (Figure 1). The HRAM dataset of the Horn River Basin is derived from a survey owned by Fugro Airborne Surveys. This survey was flown with a flight line spacing of 400m oriented NE/SW and a tie line spacing of 1200m oriented EW and with a draped ground clearance of 100m. Fugro performed limited cultural editing on the survey lines in order to remove artifacts related to oil wells and pipelines in the area. The reduced to pole total magnetic intensity and the horizontal gradient grids of the HRAM data are displayed in Figures 2 and 3, respectively. These two grids are shaded in the NE direction and draped on the SRTM-derived topography of the area. They display the major geological and structural textures and trends in the HRAM data especially the various terrane boundaries and the prominent NS-trending Bovie Fault Zone.

The Horn River Basin is located at the border of the Foothills thrust belt with the Western Canada Sedimentary Basin (WCSB) and it is separated from the Liard Basin to the west by a prominent NS trending Bovie Fault Zone (Fig. 4). The study area is intersected by at least three main Precambrian litho-tectonic magnetic basement terranes (Fig. 4); Nahanni at the center, Fort Simpson Magmatic Arc to the east, and Fort Nelson Magmatic Arc to the west. The Precambrian basement terranes in the WCSB have been interpreted from the amplitude, texture and trends of the regional aeromagnetic data in conjunction with gravity data and isotopic age dating of Precambrian drill cores (Pilkington *et al.*, 2000). The Fort Simpson and Fort Nelson Magmatic Arc Terranes have distinctive NS trending magnetic highs. These two Terranes are characterized by the presence of ferrimagnetic minerals, most likely magnetite, which has a sufficiently high susceptibility to produce the high amplitude anomalies characteristic of these terranes. Such large magnetization is usually indicative of calc-alkaline igneous rocks associated with magmatic-arc environments. The Nahanni terrane which is associated with a magnetic low is interpreted as thinned Fort Simpson basement (Cook *et al.*, 1999).

The Precambrian basement in the study area is covered by sedimentary rocks of the Devonian Horn River Basin. The Horn River Basin contains a sequence of stratigraphic horizons and plays that are considered potential for shale gas exploration. The main formations of interest for shale gas exploration in the Horn River Basin include the Devonian Muskwa shale and Evie shale (Walsh *et al.*, 2006). A generalized geological cross-section across the Horn River Basin showing the main exploration targets including buried channels and faults is shown in Figure 5.

## Conclusions

The Laplace, the SDGD and the PLUS filters appear to be powerful tool in detecting buried channels, faults, fractures and other shallow geological features in HRAM data. In addition to detecting shallow geological features, these filters appear to be useful in mapping various textures in the area. These textures may reveal various geological domains in the Horn River Basin.

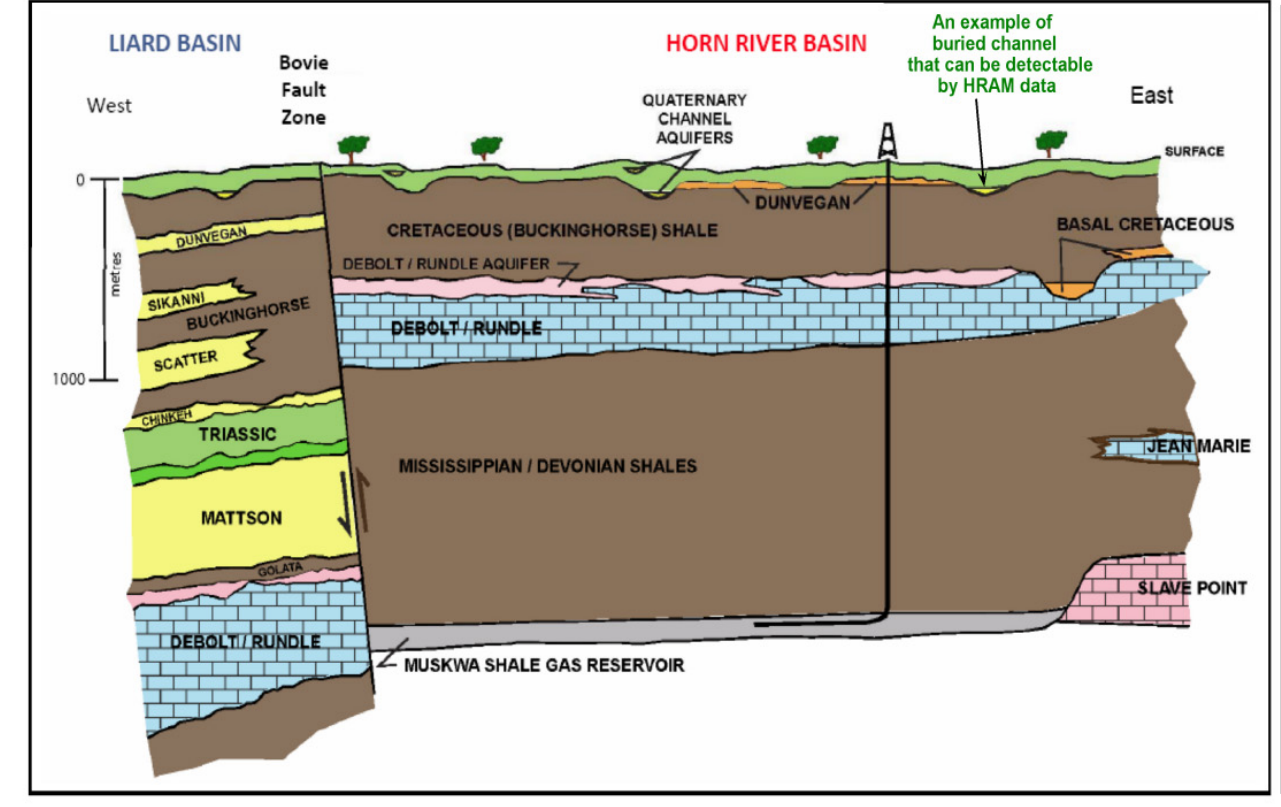
LIARD BASIN
West
Bovie Fault Zone
HORN RIVER BASIN
An example of buried channel that can be detectable by HRAM data
East
QUATERNARY CHANNEL AQUIFERS
SURFACE
0
metres
1000
DUNVEGAN
SIKANNI
BUCKINGHORSE
SCATTER
CHINKEH
TRIASSIC
MATTSON
GOLATA
DEBOLT / RUNDLE
CRETACEOUS (BUCKINGHORSE) SHALE
DEBOLT / RUNDLE AQUIFER
BASAL CRETACEOUS
MISSISSIPPIAN / DEVONIAN SHALES
JEAN MARIE
SLAVE POINT
MUSKWA SHALE GAS RESERVOIR

Figure 5. Generalized geological cross-section across Horn River Basin (after Petrel Robertson Consulting Ltd., 2010).

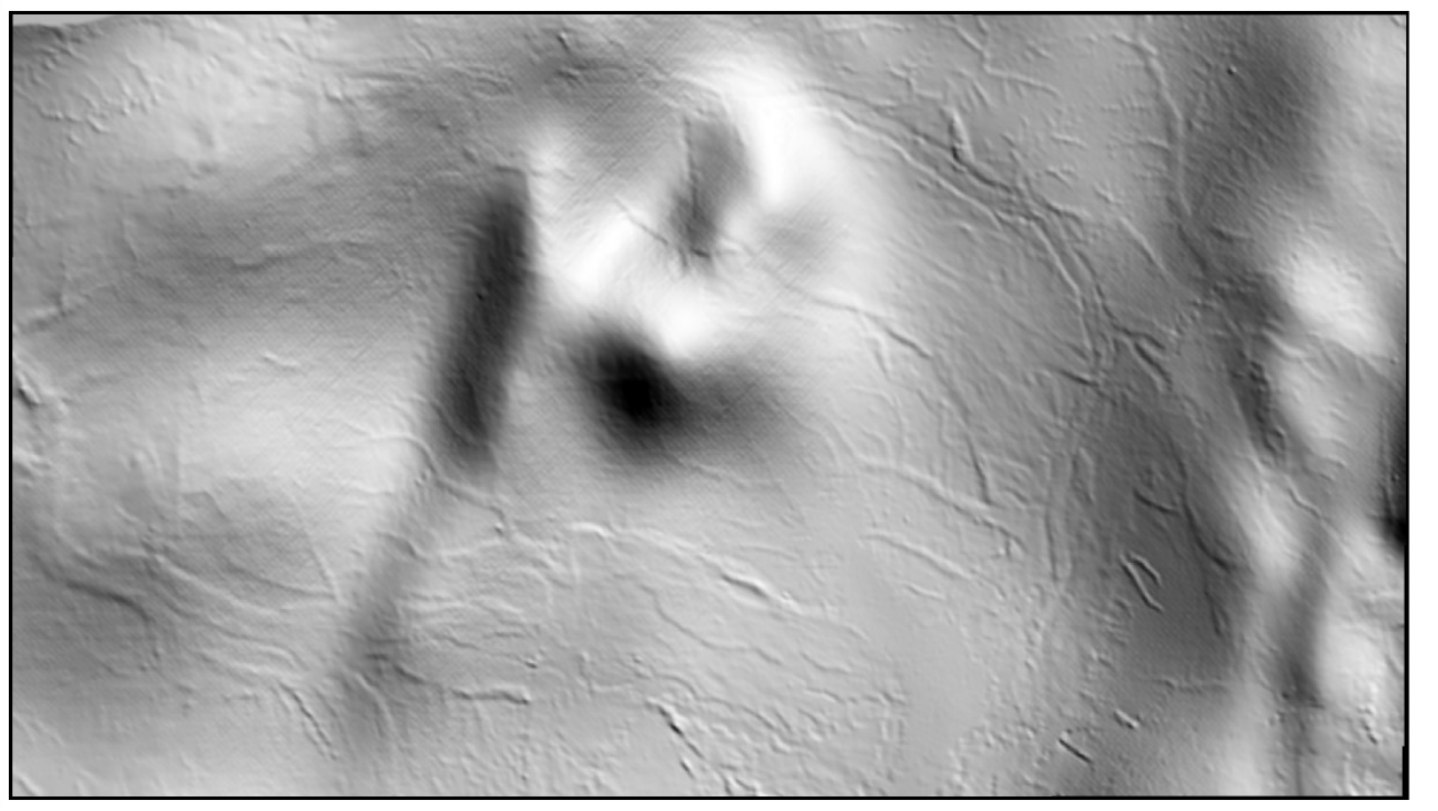

Figure 6. Image of RTP grid used as an input in calculating Laplace, SDGD and PLUS filters shown in Figures 7, 8 & 9.

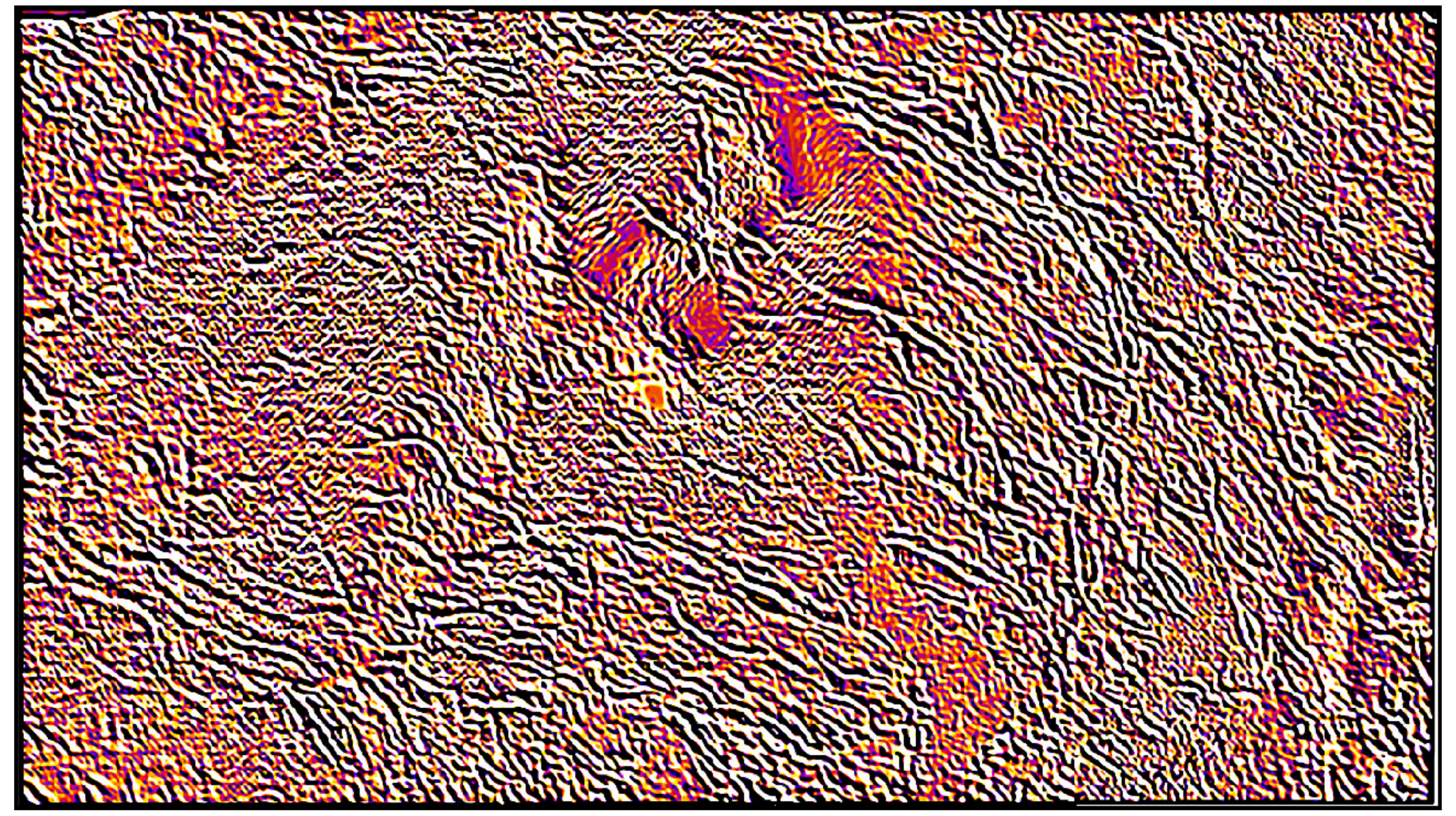

Figure 7. Results of applying Laplace filter on the RTP image shown in Figure 6.

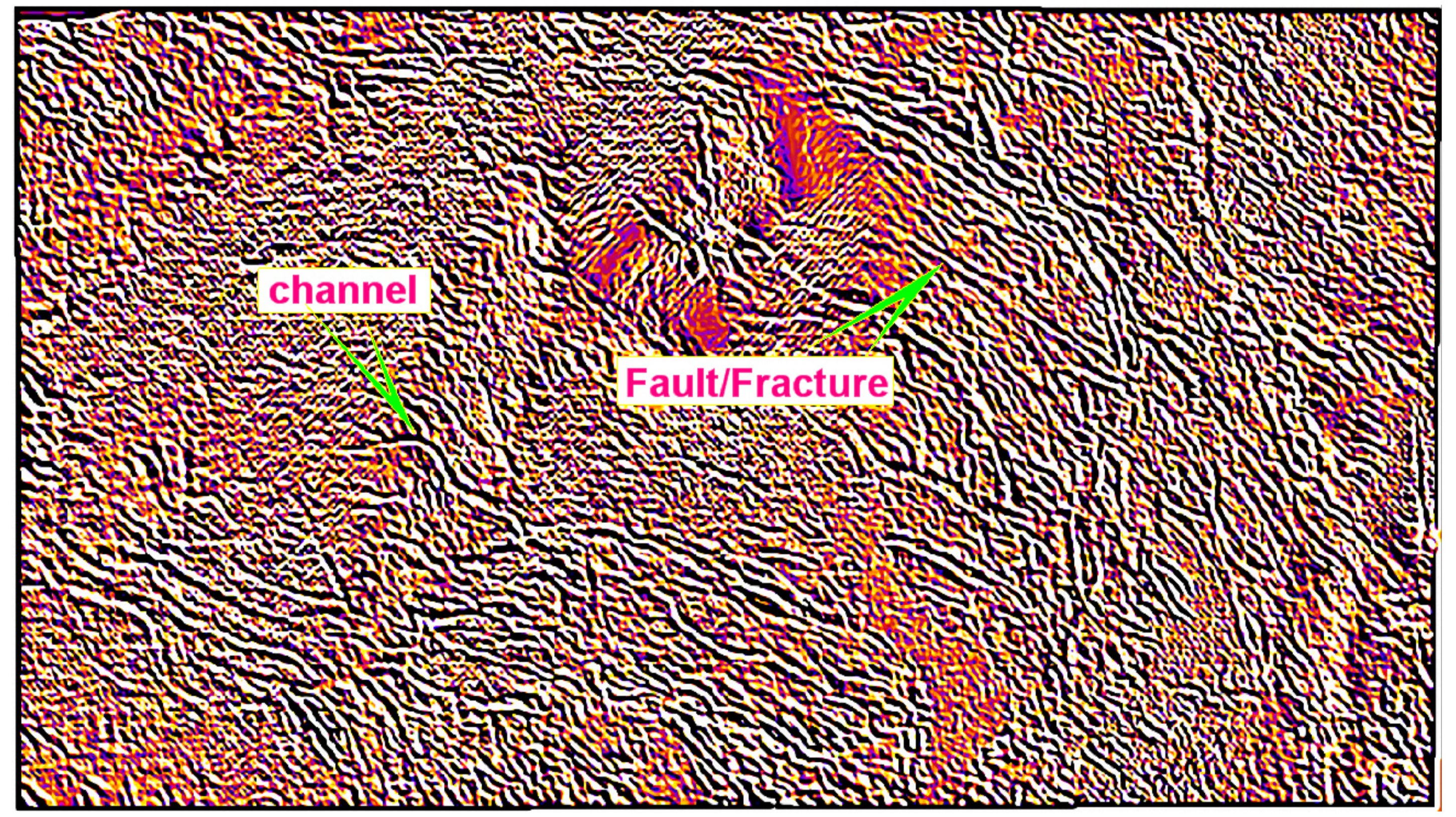
channel
Fault/Fracture

Figure 8. Results of applying SDGD filter on the RTP image shown in Figure 6.

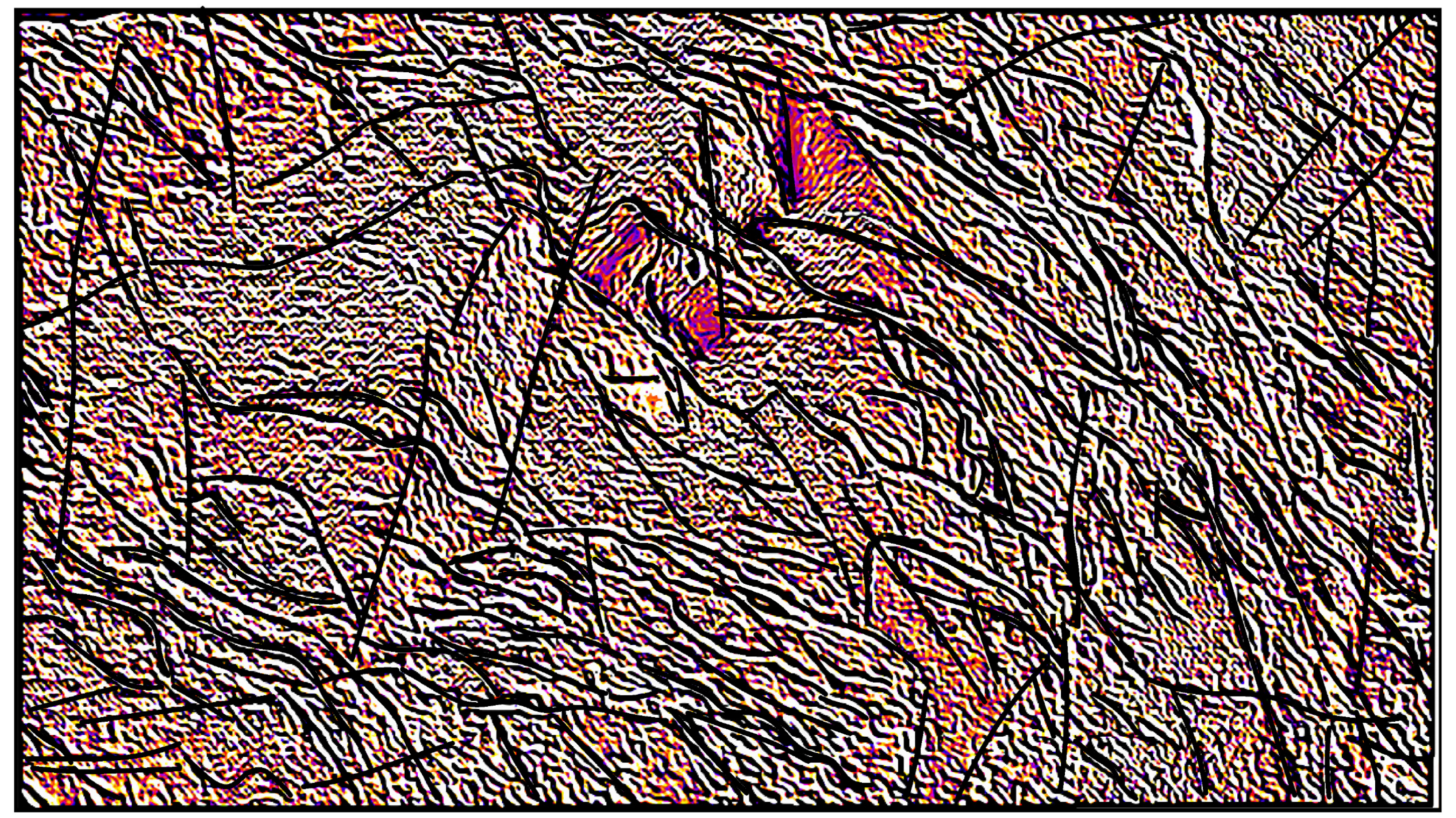

Figure 9. Preliminary analysis of lineaments extracted from the results of PLUS filter.

## Methodology

The HRAM data selected for this study is outlined as a white box in Figure 4. An image of the reduced to pole (RTP) total magnetic intensity grid, within this box, was used as an input in the calculation of the Laplace, the SDGD and the PLUS filters. The input RTP image is shown in Figure 6. The Laplace, the SDGD and the PLUS filters were developed at the Delft University of Technology, Netherlands (van Vliet, 1993; van Vliet and Verbeek, 1994) and they are robust in detecting subtle contrasts in images that are, in case of HRAM data, attributable to geological features.

Prior to applying the Laplace, the SDGD and the PLUS filters on the RTP image of the Horn River Basin (Fig. 6), we suppressed the level of noise in the data by multiplying the RTP image by a low-pass Gaussian filter. Afterward, we have calculated the Laplace, the SDGD and the PLUS filters using the following partial derivatives:

$$A_{xx} = \frac{\partial^2 a}{\partial x^2} \qquad A_{xy} = \frac{\partial^2 a}{\partial x \partial y} \qquad A_x = \frac{\partial a}{\partial x}$$

$$A_{yx} = \frac{\partial^2 a}{\partial x \partial y} \qquad A_{yy} = \frac{\partial^2 a}{\partial y^2} \qquad A_y = \frac{\partial a}{\partial y}$$

Since $\boldsymbol{A_{xy} = A_{yx}}$ , then only five of these derivatives were used in SDGD calculation.

The Laplace filter is the sum of second derivatives in the x and y directions and mathematically expressed as follows:

$$LAPLACE = \left(A_{xx} + A_{yy}\right)$$

The SDGD (also termed the second directional derivative) is calculated using the following formula:

$$SDGD = \left(\frac{A_{xx}A_x^2 + 2A_{xy}A_xA_y + A_{yy}A_y^2}{A_x^2 + A_y^2}\right)$$

The sum of *SDGD* and the Laplace filter is called the PLUS and it was calculated using the following formula:

$$PLUS = \left(\frac{A_{xx}A_x^2 + 2A_{xy}A_xA_y + A_{yy}A_y^2}{A_x^2 + A_y^2}\right) + \left(A_{xx} + A_{yy}\right)$$

## Results

The effects of applying the Laplace, the SDGD and the PLUS filters on the RTP image of the HRAM data are illustrated in Figures 7 to 9. The Laplace image (Fig. 7) clearly displays geological patterns that might be indicative of shallow geological features such as buried channels, faults and fractures. These features appear to be enhanced further on the SDGD and the PLUS images (Figs. 8 and 9, respectively). For illustration purpose, we performed a preliminary lineament analysis on the results of the PLUS filter (Figure 9). In addition of detecting geological features such as buried channels, faults and fractures in the Horn River Basin these filters appear to be good at mapping various textures in the study area.