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Feras Al-Obeidat
Zayed University

Leonardo Feltrin
Western University

Farhi Marir
Zayed University

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Cloud-Based Lineament Extraction of Topographic Lineaments from NASA Shuttle Radar Topography Mission Data

Feras Al-Obeidat[a,*], Leonardo Feltrin[b], Farhi Marir[a]

[a]*College of Technological Innovation, Zayed University, UAE*
[b]*Department of Earth Sciences, Western University, London, Ontario, N6A 5B7 Canada*

Abstract

This paper presents initial results of a Java[TM] based, feature extraction tool, which represents a standard implementation of a hill-shading algorithm that transforms a 2D image to pseudo 3D image to enhance edge contrast in combination with an edge detection Canny algorithm that performs segmentation to produce multidirectional sun-shaded images and their edges. Our goal is to firstly automate this processes in Java[TM] to obtain multidirectional optimization of edge discovery and secondly scale this algorithm to the complete SRTM raster collection at multiple pixel resolutions to document the distribution of Earth topographic discontinuities from continental to regional and local scales, respectively on the order of 1000s, 100s and 10s of kilometers. This tool will support the automatic extraction of lineaments of the transformed images to predict the existence of linear features that can be often found in association with ore deposits and landslides, if they represent tectonic lineaments. The collection of processed big data, represents a multi-scale data repository that may find use for these and other geological and environmental applications. We present preliminary outputs from a case study conducted in the Flin-Flon greenstone belt in Canada, which is well known for its base-metal endowment. In this study, two main shaded relief images with multidirectional illumination were created in Java each with four azimuth angles of the light sources and from which our developed tool extracts automatically multiple lineaments. The extracted lineaments represent both positive and negative elevation breaks, due to sudden slope inversions identifying dominantly crest lines and valleys. Preliminary results show good agreement with drainage networks, mapped fault lines and orientations of structures measured in the field. The main trends of the extracted lineaments of both images are NW-SE, N-S, E-W and NE-SW.

Keywords: DEM; Shaded relief; Edge Detection; Image classification, Mineral mining; Automatic lineaments.

1. Introduction

Hydrothermal ore deposit formation is a process that involves stochastic and deterministic components[1]. The deterministic processes can be represented in a GIS framework as geospatial criteria, and interpreted as being representative of optimal proximity factors, controlling mineral deposit location[2]. Most mineral exploration activity relies heavily on geological interpretation to study and record the distribution of topographic discontinuities in GIS

* Feras Al-Obeidat. Tel.: +971-259-93371
E-mail address: feras.al-obeidat@zu.ac.ae

systems at various scales[3]. This activity is carried out to detect potential fault zones. Faults during earthquake induced activation become primary conduits to mineralizing fluids[4]. Fault ruptures are also potential traps for mineralization in post-seismic sealing episodes, thus it is important to map faults to increase the chance of locating new hydrothermal mineral deposits[2,5]. Capturing tectonic lineaments is a time consuming process that leads to subjective judgment, and may not be accurate or sufficiently detailed, in most cases. Mining and exploration is a costly business to run, particularly when exploring remote areas to conduct mineral exploration programs. It is therefore essential to any mineral exploration venture to obtain up to date digital information that facilitates the identification of mineral resources, reducing economic risk[6]. In this context, computer algorithms that automate and facilitate lineament detection/extraction are an important area of research[7,8,9,10], having the potential to facilitate geological interpretation and reduce the time required to compile this type of structural geology map products.

In this paper, we present preliminary results of an analytical tool developed using existing hill-shading open source algorithms that give a two dimensional (2D) map of terrain a three dimensional (3D) appearance[6] by increasing contrast where abrupt changes of topography occur as in crests and valleys. This initial processing generates automatically multiple raster images in greyscale form corresponding to different sun-shading illumination/inclination angles, subsequently each product is again automatically passed to a Canny edge detection algorithm[3] to extract lineaments from the multidirectional sun-shaded SRTM (Shuttle Radar Topography Mission) data[5]. SRTM digital elevation data, produced originally by NASA, represent a major innovation in digital mapping of the world, being of high quality, with almost global coverage. Furthermore, recent 1 arc-second releases (approximately 30 m resolution which is three times more accurate than previous NASA 3 arc-second products at 90 m pixel resolution) includes all of South America and North America, most of Europe, and islands in the eastern Pacific. In general, both SRTM data sets given their global coverage are big-data exceeding several gigabytes of information. On top of this, after application of our tool, the size of the data base increases several times due to the multidirectional processing products exceeding the terabytes of information.

This preliminary study is similar to the work reported in[1] and[2] who used PCI Geomatica[4]; however in contrast to these authors we directly implemented hill-shading and the Canny algorithm using Java and its plug-in based environment, offering more flexibility and integration with big data analytics systems such as HBase for NoSQL storage of information, MapReduce for parallel computations on a cluster of machines as part of Apache Hadoop ecosystem. The implementation in Java[TM] can facilitate scaling of the algorithms to a web application interface for distribution of information as in common Service Oriented Architectures (SOA).

This contribution is organized as follows: the current Section 1 briefly overviews and introduces the objectives of this study. Section 2 presents the geological context of the study area. In Section 3, we present the algorithms the analytical/extractor tool implementation. The tool application and the experimental study is presented in Section 4. Finally, conclusions and future work are presented in Section 5.

2. Geological Significance of the Study Area

VMS deposits are an important source of base-metals for the global economy. The Flin Flon Domain comprises a collage of Paleoproterozoic volcano-plutonic assemblages derived from different tectonic environments, progressively juxtaposed during the ongoing Trans-Hudson Orogeny (1.84 1.69 Ga). This poly-deformed terrane is well endowed with VMS deposits (e.g., Flin Flon, 62.4 Mt, prod. plus reserves), found in dominantly juvenile (mantle derived), primitive arc-rocks, commonly associated with discrete felsic rock assemblages. Rocks of the Flin Flon-Domain are, however, only partly exposed. The Precambrian belts are covered by Phanerozoic, carbonate and clastic units of the Western Canada Sedimentary Basin in their southern termination, inhibiting exploration for VMS mineralization. Our study considered the western part of the Flin Flon Belt (FFB).

The study area in this paper is located in Saskatchewan which corresponds to the western termination of the Flin-Flon domain. Fig.1 presents the Flin-Flon study area from two perspectives: Fig.1a describes the mapped locations of mineral deposits and occurrences in Flin-Flon area. Based on their distribution, one can notice that the geographic location is biased, with most of the showings and deposits (including Flin Flon) found in the northern domain where the Flin Flon metavolcanic belt is exposed. Fig.1b presents the SRTM digital elevation map on a near-global scale from 56 S to 60 N, generating the most complete high-resolution digital topographic for the Flin-Flon area.
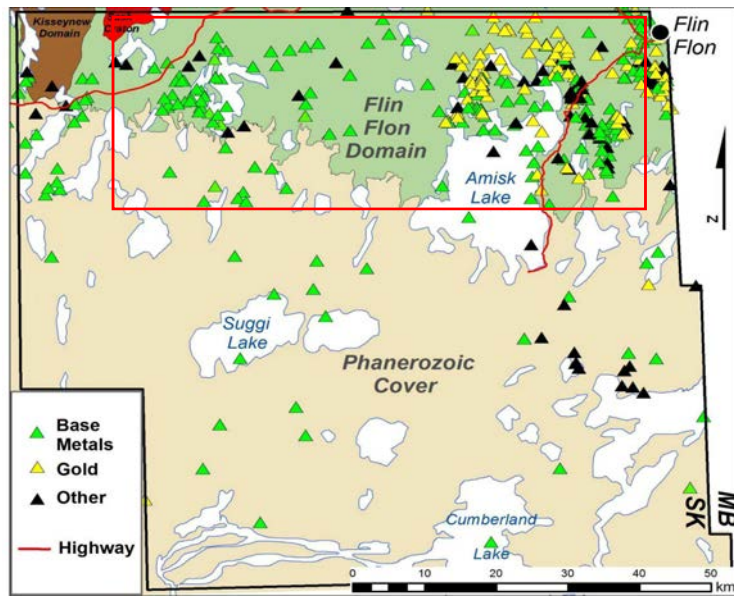
(a) Study area illustrating the localization of the western termination of the Flin Flon Belt in Saskatchewan.
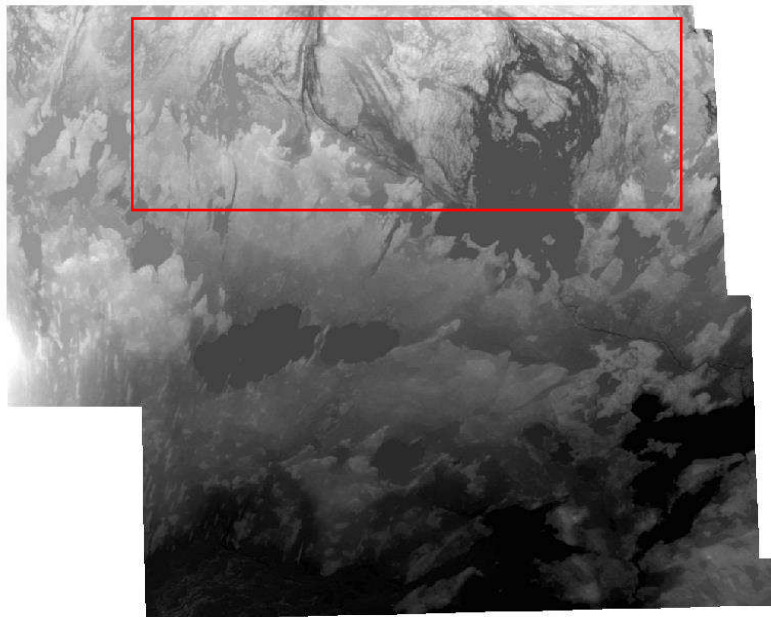
(b) The interpretation of the significance of a discontinuity in topographic data is a complex subject since there is significant uncertainty on the origin of these features.

Fig. 1: SRTM data set covering the Flin Flon area, in general it is possible to see a change in elevation with more depressed domains in the southern portion of the map. Instead the northern termination has more abrupt changes in topographic elevation with clear evidence of tectonic lineaments in a broadly higher elevation range. The red outline indicates the selected study area for lineament extraction.

3. Why Developing a Java^{TM} systematic feature extraction tool and its structure

Edge enhancement leads to image sharpening, in which the geometric details of an image may be modified and enhanced[7],[11] (Figures 2, 3). Features such as lineaments, drainages and certain landforms are often characterized by abrupt changes in radiometric responses. Edge enhancement is a useful and efficient technique to magnify these features, facilitating their visual and automatic detection. The Java^{TM} based analytical tool we developed is capable of automating this process by calculating the shaded-relief response of a DEM, from multiple angles of illumination. This process adds and additional level of processing and is particularly useful to resolve the problem of shadowing of smaller scale lineaments occurring when a single direction and angle of illumination is adopted in the processing of the images for edge contrast determination.

Techniques of shaded relief have been used in cartography to produce the illusion of a three-dimensional relief map. During the last decade, digital image processing techniques have been developed to display DEMs as shaded relief images. In the case of DEMs, shaded relief images and terrane derivative products (slope, aspect and curvature calculations) have largely demonstrated their usefulness for lineaments and fault mapping[7]. Together with such developments in image analysis, the digital revolution in particular the filed of parallel computation has augmented exponentially our capacity of processing information changing the way other scientists manage an process information to derive patterns and large scale semantics. This Java^{TM} implementation is then proposing to bridge these disciplines to save the time commonly wasted in reprocessing for instance SRTM data at project level in a multitude of case studies like the one briefly illustrated.

If we consider in more detail the structure of the proposed analytical tool: different steps of analysis are presented in Algorithm 1. These consist in firstly developing a prototype code implementing two major image processing algorithms, as mentioned earlier: (1) a multi-directional Hill-shading algorithm to transform 2D raster images into pseudo 3D raster images and (2) a Canny Algorithm to perform multidirectional edge detection on a given SRTM data set. In a secondary phase the project seeks to leverage on cloud computing to achieve a higher level of automation and representation of the processed dataset at various scales, with the objective of systematically analyzing the entire NASA-SRTM data collection.

In this preliminary study, the tool produced several shaded relief images facilitating testing and illustrating some of the pitfalls encountered when attempting automatic edge extraction procedures. Different values for solar azimuth and solar elevation were tested by changing the angles value of both parameters, to obtain probabilistic estimates of the likelihood of a lineament being present at a specified pixel location in the SRTM raster tiles. The objective was to minimize the effect of directional illumination and increase the efficiency of the tool in capturing the distribution of linear features observed. Some of the pitfalls observed revolves dominantly around the use and interpretation of the origin of these linear features that often resemble either human impact on land or the presence of water especially at the latitude considered for this study in Canada. More advanced versions of the tool will consider blending with other data sources (e.g., geophysical data such as GRACE) to increase our ability of automatically discriminate different natural processes leading to the formation of topographic discontinuities.

Further details on the algorithm consider also: (1) algorithms were coded with two major open source libraries: JGrass and ImageJ. (2) The Analytical tool first reads the original SRTM data in a form of GeoTiff image letting the user to change the parameters: azimuth and elevation for the study area, (3)The analytical tool generates shaded area and produces a series of GeoTiff images that can be displayed by image viewers such as ArcGIS, then it identifies edges and important areas of the produced shaded images. A more detailed summary illustration, is given in Algorithm 1.

The final phase for the development of the analytical tool concerns the design of a generic portal for product distribution at various scales of analysis. This represents future work in the project however we foresee a transition of this tool in a computational framework that uses the Hadoop ecosystem since this platform is fully open source and has a large community of contributors and developers. This ecosystem is particularly appealing because of the capacity of storing image data in HBase and also significant processing capacity with the Spark environment (e.g. MLlib project). Although this project is in its infancy significant progress is allowing use of Machine Learning (ML) algorithms (and other statistical segmentation/classification algorithms, such as the one discussed in this paper) that are being actively and successfully used by a disparate group of industries. This suggests that customization and

tailoring of some of these tools or newly developed tools to the geoscience might represent a significant progress in solving Big Data geoscientific problems such as the ones found often in remote sensing.

Algorithm 1 The Developed Algorithm and Data flow

1: **procedure** EXTRACT ALIGNMENT ACCORDING TO AZIMUTH (z) AND ELEVATION (e) VALUES
2:     Read SRTM-Data GeoTiff Images
3:     **for** each value $e \in 25, 45, ...$ **do**
4:         **for** each value $z \in 45, 90, 225, 340, ...$ **do**
5:             Apply Hill-shade code using based on e and z i.e. azimuth and elevation
6:             Generate Hill-shade images g
7:             Apply edge detection code on g to discover topographic details
8:             Generate edge detection images $g^`$
9:         **end for**
10:    **end for**
11:    classify and analyze the generated images $g^`$ according to their similarity.
12: **end procedure**

Given the scale of analysis (100s of square kilometers) in this initial case study a series of tests were run on a tile of SRTM data of 90 m pixel resolution. These DEMs have a resolution of 90 m at the equator, and are provided in mosaicked 5 deg x 5 deg tiles for easy download and use. The interpretation of the significance of a discontinuity in topographic data is a complex subject since there is significant uncertainty on the origin of these features as shown in Fig. 1b. Commonly lineaments may form in response to abrupt morphological variation induced by hydrogeological or geological processes. Even if such uncertainty exists, probabilistic models can be used to reduce ambiguity based on this imprecise knowledge[7]. Figures (2-3) represents preliminary outputs using different directions of solar azimuth and solar elevation.
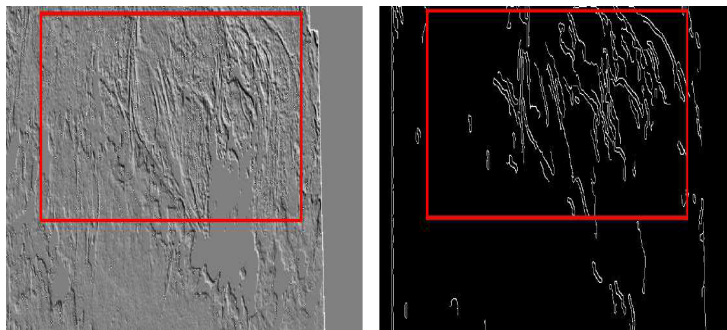

Fig. 2: Application of Hillshading and Feature Detection: Elevation=25, Azimuth =225.

4. Analysis of the results and Conclusions

Results obtained suggest as expected that depending on the orientation of sun-illumination the strike of detected lineaments vary accordingly. Our examination of the Canny performance in mapping edges show that the algorithm performs differently as a function of topographic relief. Topographically depressed areas contain linear features that are not detected in the Canny-detection algorithm. If we look at results obtained in the highlighted NW corner of the map we note a better performance because of the increased elevation.

This result is also attributed to the different nature of the geological units in this area which are represented by exposed Archean shield rocks of the Flin Flon Domain. Specifically, in the same area the feature extraction algorithm
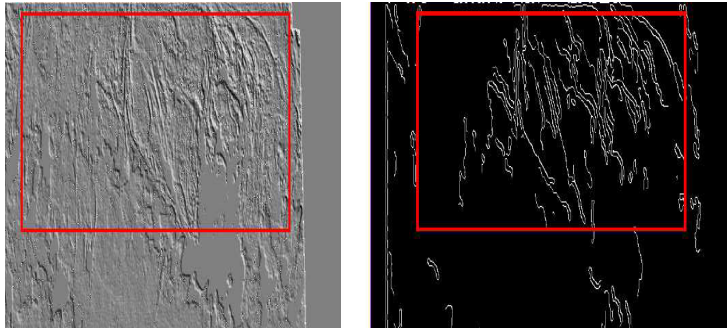
Fig. 3: Application of Hillshading and Feature Detection: Elevation=45, Azimuth =225.

appears to identify geological contacts. The preliminary results are encouraging given the importance of contacts between felsic and mafic intervals in this particular area. Future work will focus on more detailed interpretations of this part of the shield as well as fulfilling highlighted objectives discussed in previous sections.

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