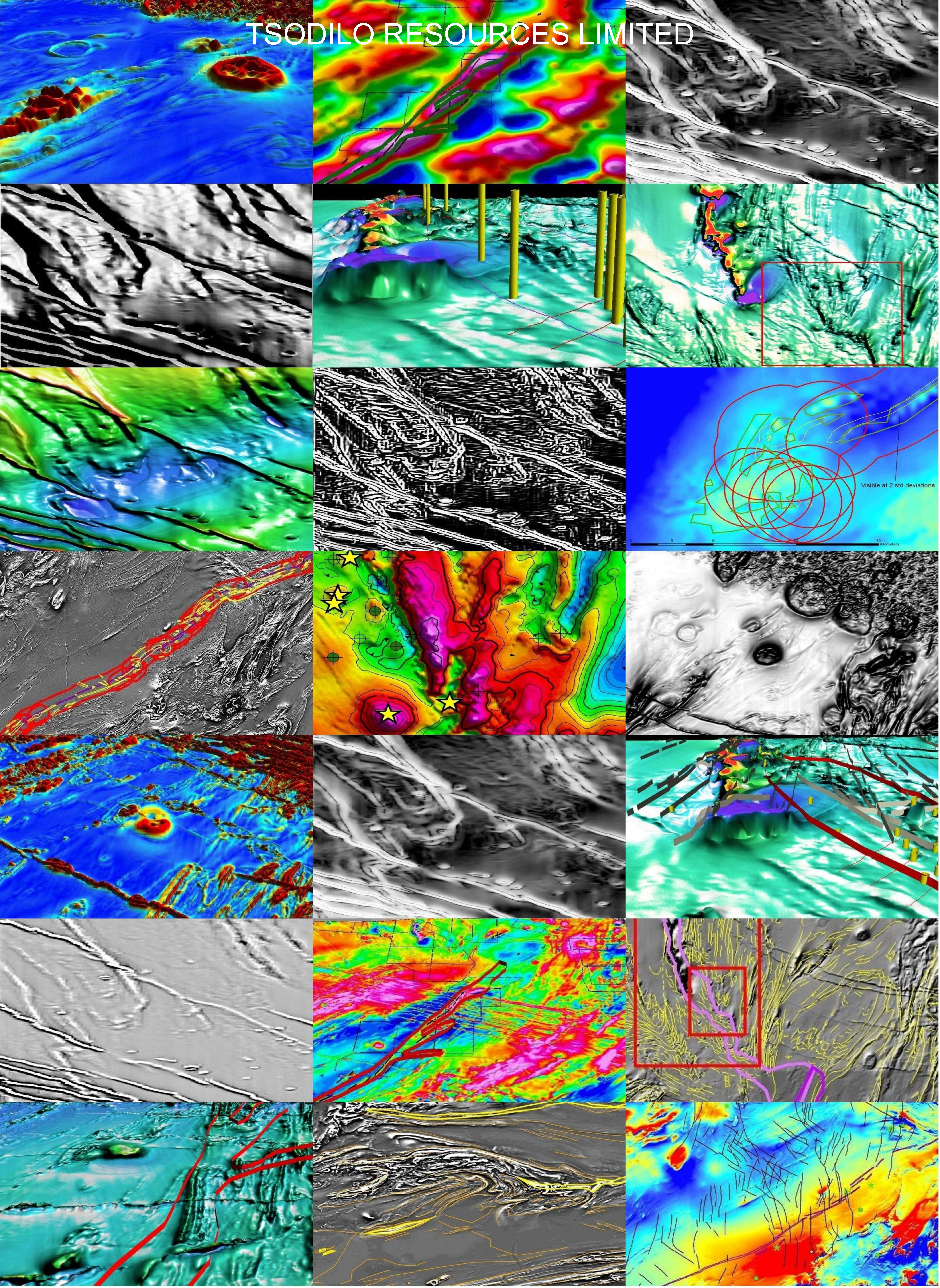TSODILO RESOURCES LIMITED

Tsodilo Resources Pty Limited uses GIS techniques for base metal exploration and kimberlite targeting in NW Ngamiland (Botswana) – a case study exhibiting the potential for 3-D visualization of aeromagnetic terrain data and improved feature extraction based on ERDAS IMAGINE®, ER Mapper®, IMAGINE Virtual GIS® and ArcView® software.

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Introduction

GIS has become an integral part of the information processing workflow in the exploration and mining sector. The systems range from huge corporate data infrastructures applied by global giants such as DeBeers to the smaller desktop GIS typically applied in junior diamond and base metal exploration companies. In both settings the GIS is the focal point for applications such as managing prospecting license data, satellite image processing, geophysics data processing, regional exploration analysis, structural mapping, reporting and so forth. In this article we examine how some existing desktop GIS tools (ERDAS®, ER Mapper®, IMAGINE Virtual GIS® and ArcView®) have been applied in base metal exploration to trace the Matchless Amphibolite Belt Extension (MABE) through NW Ngamiland (Botswana) (figure 1). We also examine how these tools have been applied to map lithotectonic trends in the Pan-African Basement, improve the feature definition of kimberlite targets in aeromagnetic data and to create 3-D visualizations of the associated data.

ERDAS® has developed a particularly powerful package for 3-D visualization that integrates superbly with the GIS outputs from other systems. Examples of the power of IMAGINE Virtual GIS® are clear from its application to Landsat image drapes for geomorphologic applications (Eckardt, 2008). These visualizations are powerful, but as hard rock geologists and geophysicists one is left with the question can these tools produce equally impressive vistas of the subsurface geology? The answer is yes and this article aims to illustrate this potential. By applying data processing techniques currently utilized for impact crater definition and geophysical exploration (Cooper, 2008; Cooper et al., 2009) in a GIS environment we have developed a technique which produces comparable (possibly aesthetically improved) results in a way that is seamlessly integrated with the existing GIS data.
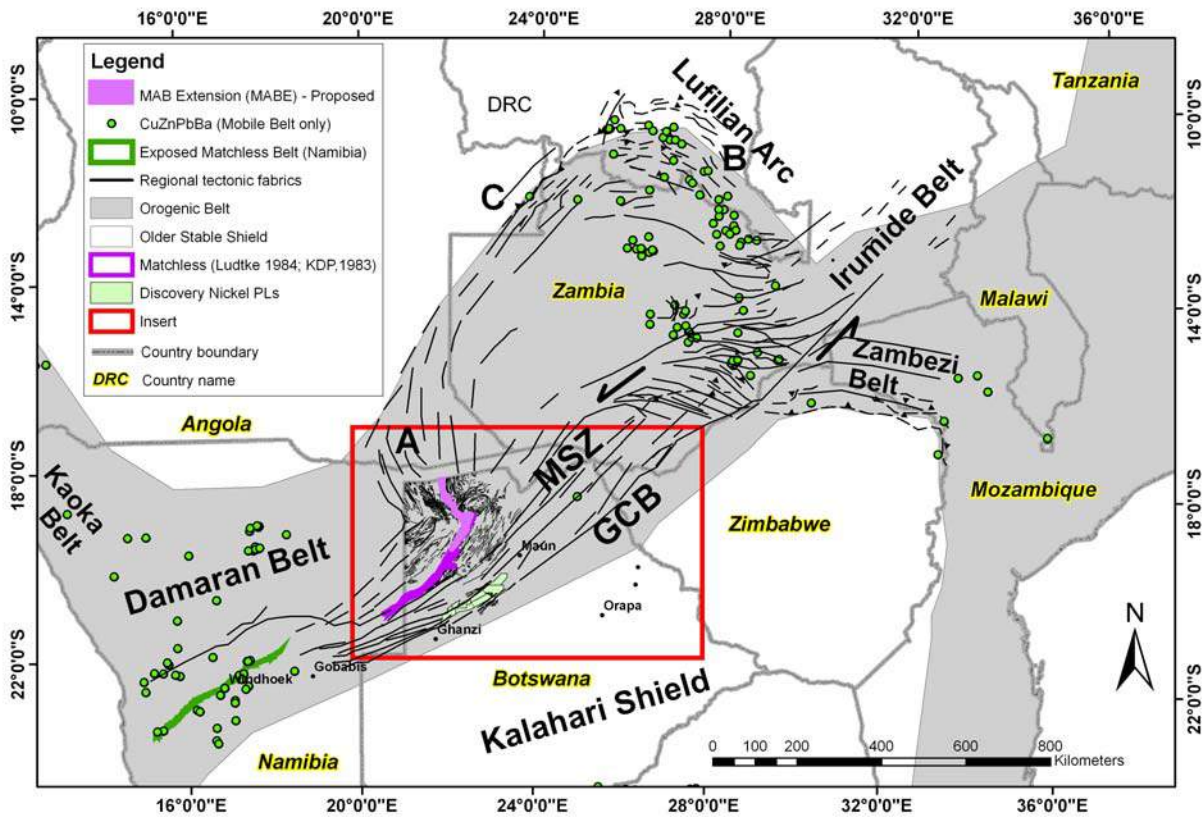
Feature definition tools

The ability to improve feature definition in aeromagnetic data is critical to kimberlite exploration. This can be achieved by applying specialized geophysics data processing routines developed in technical computing languages such as Matlab® (Cooper, 2008). The application of such routines can sometimes involve a loss of spatial information, requiring that the processed data be georeferenced before it can be integrated with an existing GIS. Below we examine some existing GIS image (e.g. hillshading, slope, convolution filters) and geophysical data processing tools that may be applied to achieve comparable results without the loss of spatial information. These methods were tested on aeromagnetic data covering the Nxau Nxau kimberlite field in NW Ngamiland and are discussed in greater detail in Martinez (2009).

Total Horizontal Gradient & Hillshading (ArcView ® Spatial Analyst)

The Spatial Analyst extension of ArcView® is an excellent starting point to improve the feature definition quality of aeromagnetic data. In particular the slope function[1] and hillshading[2] tools can be used to calculate the total horizontal gradient and produce impressive enhancements of the imagery for geological mapping (figure 2). The square root (and higher powers) of the total horizontal gradient image may also be easily calculated using the map algebra raster calculator[3]. The hillshading algorithm may be used as a high pass filter to enhance linear structures in aeromagnetic data. However given the directional bias associated with this algorithm, it is less well suited for defining non-linear features such as kimberlite targets. Instead the Laplacian or other simple space

Figure 1. Location of the NW Ngamiland region (Botswana) examined in this work. (Reprinted from De Wit (2009): Figure 2: Regional tectonic fabrics mapped from the Total Aeromagnetic Intensity data for Southern Africa. Also shown are copper deposits, the Matchless Amphibolite Belt and Zambia Copperbelt deposits in Southern Africa. MSZ=Mwembeshi Shear Zone; GCB= Ghanzi-Chobe Belt)


domain kernel high pass filters are recommended by Cooper[4] (2009, pers.comm.). Slight modifications to the raster display options in ArcMap can also significantly impact the feature definition quality of the viewed image. Some of the factors that are useful to experiment with for the best results include viewing individual grid images (versus regional mosaics), applying inverted color ramps and varying the standard deviation parameter of stretched image displays.

Convolution Filters (ERDAS IMAGINE® 9.2)

Whereas Spatial Analyst (ArcView®) provides a good GIS-based starting point, the ERDAS IMAGINE® 9.2 products provide a range of specialized in-built image filtering tools for feature enhancement. In particular the Convolution filtering[5] tools which form part of the Image Interpreter module enable several high- and low-pass filters to be easily tested on the aeromagnetic data. Several in-built algorithms (kernel libraries) exist at 3x3, 5x5, 9x9 and 11x11 analysis size areas for high-pass, low-pass, horizontal, vertical, Laplacian and other edge enhancement, edge detection and image sharpening filters (appendix table 1). These filters enable the directional bias associated with the hillshaded image to be circumvented. The tests run on the Nxau Nxau kimberlite field showed results similar to the total horizontal gradient with the best results achieved primarily with the high band pass filters[6] (figure 2). The kimberlite targets in the area seem best defined in descending definition quality by the 7x7: edge detect, horizontal and high pass filters. In addition to these techniques, there is a wide range of other useful image processing tools available in Image Interpreter (Spatial and Radiometric enhancement, Reliefs, Fourier analysis, Topographic analysis etc). The main limitation of these routines is that one is restricted primarily to a grayscale palette.

Figure 2. Aeromagnetic data for the Nxau Nxau Kimberlite field as processed in Spatial Analyst (ArcView®) (A,C-F), MATLAB® (B) and ERDAS® (G,H): A) Raw data, B) Tilt image (Cooper, 2008), C) Square root of total horizontal gradient, D) Hillshaded image colour ramp inverted, E) Hillshaded image overlain by raw data, F) Red-blue colour ramp applied, G) 7x7 edge enhance convolution filter on raw data and (H) 7x7 high pass filter on total horizontal gradient image.
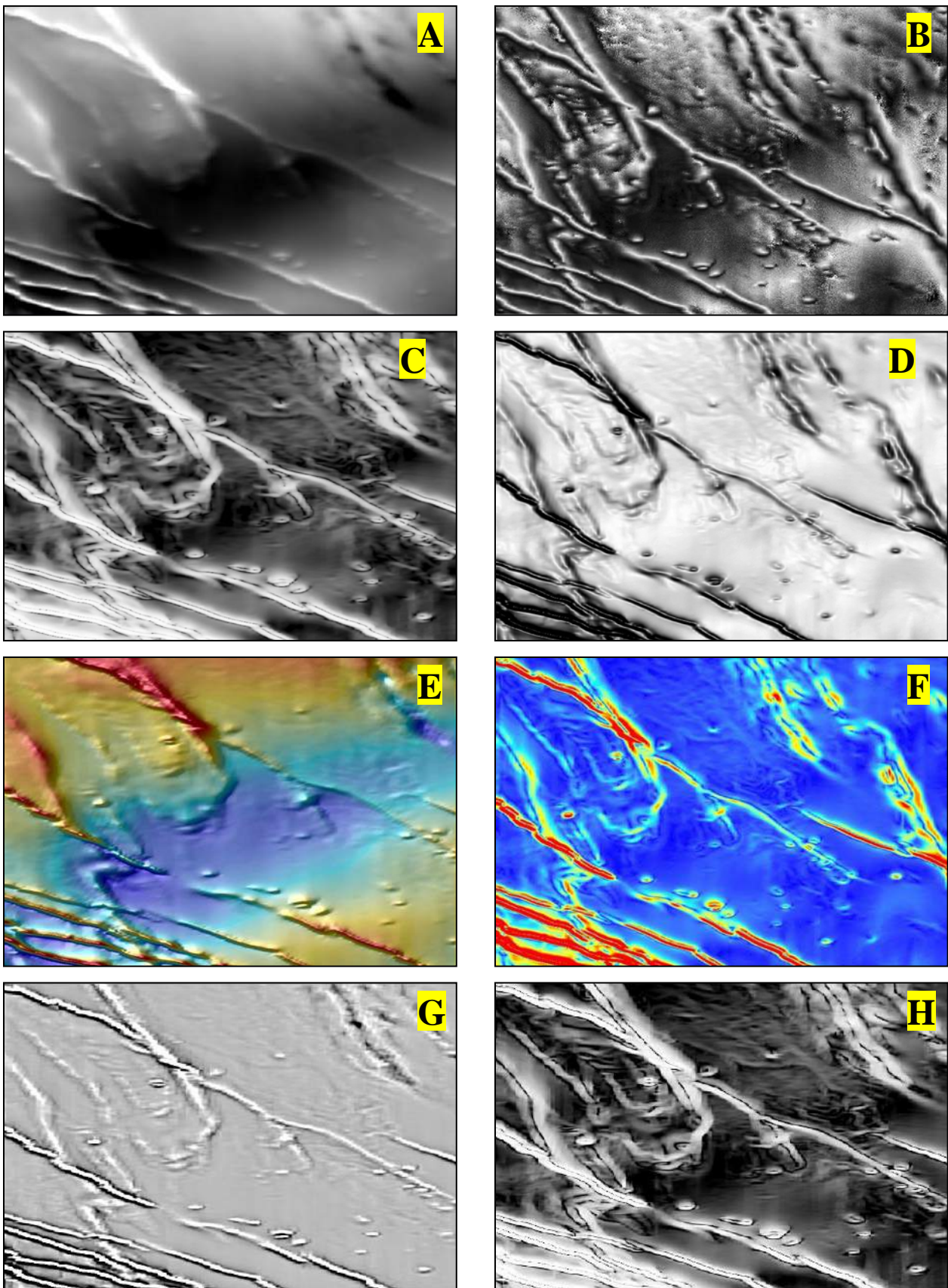
Geophysical data processing tools (ER Mapper® 7.2)
A wide range of visualization tools are included in the common geophysics images option of ER Mapper®. These include: Density sliced (pseudocolour), Shaded, Colourdraped and 3-D Perspective. In addition there is a comprehensive suite of magnetics data processing tools for structure mapping, spatial filters, frequency filters, filing voids, areas of interest and common algorithms. The spatial filters, which include a variety of Cubic fit, VD, Continuation, Analytical signal and Automatic gain control filters prove the most useful for examining aeromagnetic data. Of these the sunshaded and the NW and vertical cubic fit images seemed most useful. Overall, the best results were achieved with the structure enhanced shiny wet look magnetic data processing algorithm applied to the original aeromagnetics data (figure 3).

3-D surface modeling (ERDAS IMAGINE® 9.2, IMAGINE Virtual GIS®)
The IMAGINE Virtual GIS® module of ERDAS IMAGINE® is an extremely powerful tool for creating 3-D aeromagnetic terrain data visualizations. The color ramp limitations facing ERDAS® may be circumvented in two ways. Firstly a suitably colour ramped image drape of the total horizontal gradient may be generated in ArcMap (ArcView®). An alternative and better approach is to apply the structurally enhanced versions of the data produced in ER Mapper® as an image drape. In both cases the best results were obtained by using the total horizontal gradient as the Digital Terrain Model (DTM) with an applied vertical exaggeration. The application of these techniques to base metal and kimberlite exploration and meteorite crater mapping are illustrated in figures 4-10 and discussed further in sections below.

For the purposes of contextualizing data in schematic diagrams and for improving the overall visualization of selected scenes it is often useful to overlay vector data and in certain cases to extrude such data to the virtual or draped surface. IMAGINE Virtual GIS® enables vector data to extruded relative to the surface of interest in several ways. Examples of how point and line data such as drill hole locations and faults may be extruded as virtual drill cores and fault planes to a magnetic surface are shown in figure 7.

Mapping Structural Features (Spatial Analyst(ArcView®), ER Mapper® 7.2)
The utility of the structurally enhanced imagery for mapping lithotectonic trends in the Pan-African Basement is discussed in detail in de Wit (2009). While the hillshaded images produced in Spatial Analyst are arguably better backdrops for mapping faults and linear features associated with shear zones, the structurally enhanced imagery produced with the geophysical processing tools in ER Mapper® appear more powerful in terms of highlighting magnetically anomalous regions in the regional dataset. This is particularly useful when one is trying to gauge the relative significance of several anomalies in a regional base metal exploration program.

Regional Base Metal Exploration
The work on the Matchless Amphibolite Belt Extension (MABE) (de Wit, 2009: figures 5-9) illustrates how lithotectonic trends mapped enhanced aeromagnetic data may be used to trace base metal rich lithological units across regional boundaries. A series of positional and terrain views were created to place the Tsodilo Hills drill site and the MABE path in the context of other regional anomalies (figures 4-6)[7]. Other areas of interest in terms of base metal exploration in the region include the Discovery Metals Limited base metal project, the Kihabe anomalies and anomalous crater / ring-like features. It may be seen from these images that the proposed MABE (de Wit, 2009) in the Tsodilo Hills drill site area has distinctly high anomalous aeromagnetic data values relative to the region as a whole and is similar in magnitude to that encountered in the Discovery Metals Limited area (figures 4-5). These images illustrate how the regional mosaic can be more useful for gauging relative magnitudes of different anomalies in a large area.

Figure 3. Images processed using the ERDAS® Imagine Interpreter Relief (A) and NW Cubic Fit filter (B) tools and the ER Mapper® Geoprocessing sun shade (C), 3-D perspective (D) and structure enhanced shiny wet look algorithm for regional (E) and single grid data (F).
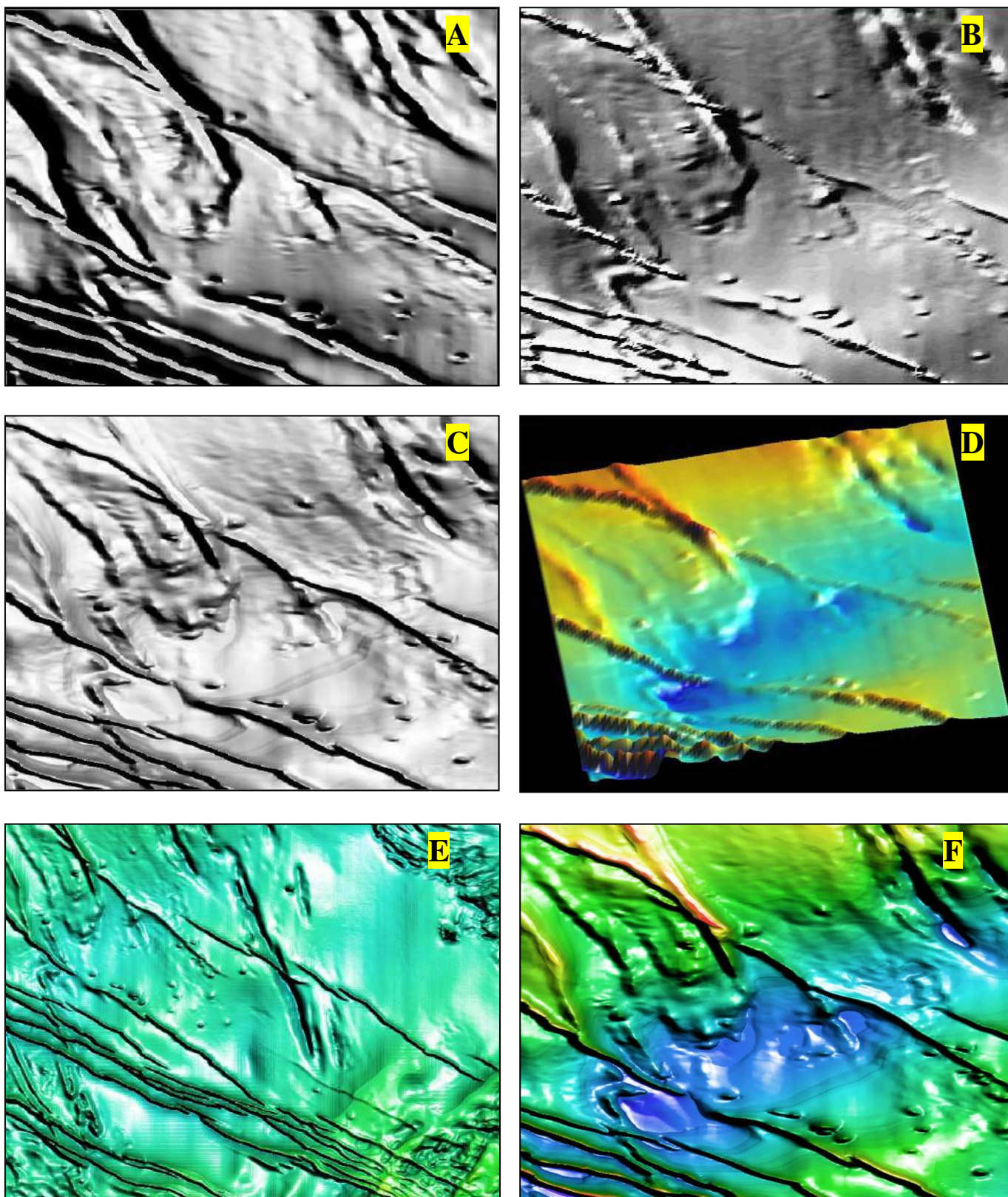
The options of overlaying and extruding vector data to a surface in IMAGINE Virtual GIS® can be very useful when constructing regional schematic diagrams for base metal exploration. These tools enable positional information such as prospecting license boundaries to be easily brought into the 3-D space. The ability to extrude data can also be useful for highlighting features of interest. Here it has been applied to highlight the Matchless Amphibolite Belt Extension (MABE) trend and fault planes relative to the regional aeromagnetic data (figure 7). When dealing with the extrusion of vectors to planar features, not only does changing the change in geometry have an impact, but other factors such as the sun angle and zooming into the view can also change the overall impression of the scene.

Other tools for base metal mapping (ArcGIS®)
All of the techniques mentioned above are powerful tools that can be used to extend the capabilities of a base metal exploration GIS for better feature definition, mapping, visualization and so forth. However, the true potential of this information can only be fully implemented in the context of other types of datasets. As such the underlying GIS platform ArcMap (ArcView®) remains the focal point for regional base metal exploration analyses (figure 8). It is in this environment that the lithotectonic data can be examined in the context of previous geological studies and other geophysical data. One of the key advantages of the techniques discussed here is that all of the 2-D processing outputs are directly compatible with the ArcView®. Similarly all of the ArcView® datasets are easily imported into the 3-D IMAGINE Virtual GIS® environment.

Kimberlite targets and meteorite impact craters
The target threshold definition tool in ER Mapper® also tool holds a high potential for identifying kimberlite targets in predominantly magnetically "quiet" areas. However, the presence of adjacent or cross cutting intrusive features such as dykes (as in the case of the Nxau Nxau kimberlite field) can make it difficult to set a target sample threshold. Furthermore, while the regional datasets seem particularly useful base metal mapping, the same is not true for kimberlite targeting applications. Marked variations are visible when the structure enhanced aeromagnetic data for the Nxau Nxau kimberlite field as generated from a single grid (M1821C) versus the regional dataset is draped over the DTM (figure 9). In these images it can be seen while the source data for generating the enhanced image is identical (where the datasets overlap in extent), there are significant differences in the final appearance depending on which dataset is applied. The images clearly illustrate the potential of these techniques for highlighting magnetic dipole anomalies typically associated kimberlite targets.

Meteorite impact craters represent another feature that can be mapped using the techniques discussed here. Such features are typically not visible in Google Earth or SRTM imagery and may also represent misinterpreted ring dykes (which are generally of particular interest in terms of base metal exploration). An examination of the regional dataset (Cooper et al., 2009) indicates a high probability that an impact crater has been detected in NW Ngamiland (figure 10).

Conclusions
The results of this work show how existing GIS-based image enhancement techniques can be very useful to highlight faulting and other linear structural features at a regional scale. Given that promising sulphide mineral targets are often associated with shear zones and fault junctions, these techniques present powerful tools for base metal exploration. At the same time the convolution filters and other geoprocessing tools discussed are excellent tools for kimberlite exploration. Given each software has its specific strengths and limitations; it seems the best results are obtained by a combined software approach.

In 2-D the total horizontal gradient of the aeromagnetic data produces a significant improvement in feature definition. Comparable results which have a better application for identifying non-linear targets such as kimberlites may be achieved by applying the ERDAS® Image Interpreter convolution filters. The best 3-D surface modeling results were achieved by draping a structure enhanced shiny

wet look aeromagnetics data image generated in ER Mapper® over a DTM of the total horizontal gradient in IMAGINE Virtual GIS®.

While this article has focussed on the treatment of only one variable (aeromagnetics data) within the 3-D space, this is just the tip of the iceberg. There are several other datasets (such as the gravity bouger anomaly, RTP-TMI, VTEM, other geophysical, geochemical and satellite imagery datasets) that would be useful to examine in 3-D. The next step is to test whether the multivariate approach typically employed in 2-D GIS can be applied in the 3-D environment in a powerful and visually aesthetic manner.

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Acknowledgments

Endnotes

[1] The Slope function calculates the maximum rate of change between each cell and its neighbours, for example, the steepest downhill descent for the cell (the maximum change in elevation over the distance between the cell and its eight neighbours). Every cell in the output raster has a slope value. The lower the slope value, the flatter the terrain; the higher the slope value, the steeper the terrain. The output slope raster can be calculated as percent of slope or degree of slope.

[2] The Hillshade function obtains the hypothetical illumination of a surface by determining illumination values for each cell in a raster. It does this by setting a position for a hypothetical light source and calculating the illumination values of each cell in relation to neighbouring cells. The azimuth is the angular direction of the sun, measured from north in clockwise degrees from 0 to 360. An azimuth of 90 is east. The default is 315 (NW).

[3] Cooper (pers.comm. 2009) pointed out that the total horizontal gradient produces an output with a very long tailed histogram, making it difficult to threshold properly and that better results will be obtained if the square (or higher power) root of the slope is imaged instead. In practise, while increasing the power reduces the tail of the histogram, no significant improvement could be detected with respect to the feature definition characteristic of the image.

[4] According to Cooper (pers.comm. 2009) when comparing the hillshaded and tilt images, the former enhances linear features with a given direction whereas the latter has no directional bias. As such, while the hillshade tool improves feature definition because it is a type of high pass filter, it is not best suited for defining non-linear features such as kimberlite targets. Given this directional bias Cooper recommends using the Laplacian filter or other simple space domain kernel high pass filters instead of sunshading.

[5] In the convolution method each new pixel value is calculated by centering the kernel over a pixel, and multiplying the original values of the center pixel and the appropriate surrounding pixels by the corresponding coefficients from the matrix. So that the output values are within the general range of the input values, these numbers are summed and then divided by the sum of the coefficients. If the sum of the coefficients is zero, this division is not performed.

[6] It should be noted that in most cases the filters did not significantly improve the results of a horizontal gradient calculation. It was also found that, in most cases increasing the kernel size to 5x5 and 7x7 significantly worsened the end result.

[7] Compared to the images produced by the colour drape generated in ArcMap, these images seem to have a more ethereal feel. More importantly, they should be more "accurate" as the drape is derived from the raw data and hence not subjected to errors induced by georefencing and image cropping.

Figure 4. Structure enhanced and hillshaded aeromagnetic data covering NW (Botswana). The inserts (A-G) show the location of positional and terrain views shown in following figures in this article. (Images produced using ER Mapper ® and Spatial Analyst (ArcView®).
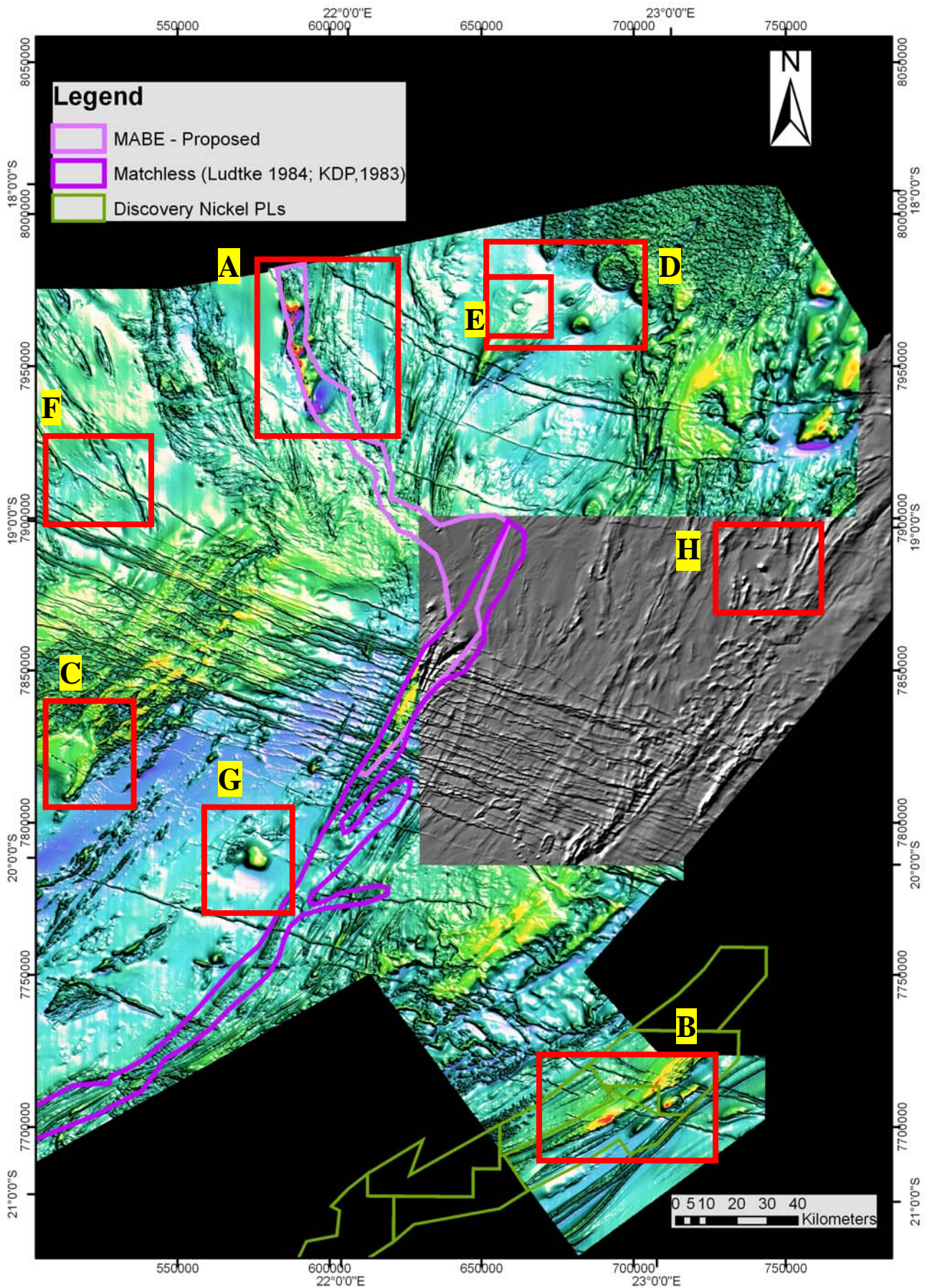
Figure 5. Positional views of regional structure enhanced data in IMAGINE Virtial GIS®. Shown are areas of base metal exploration interest: the MABE anomaly in the Tsodilo Hills area (insert A), the Discovery Metals Limited area (insert B) and the Kihabe anomalies area (insert C).
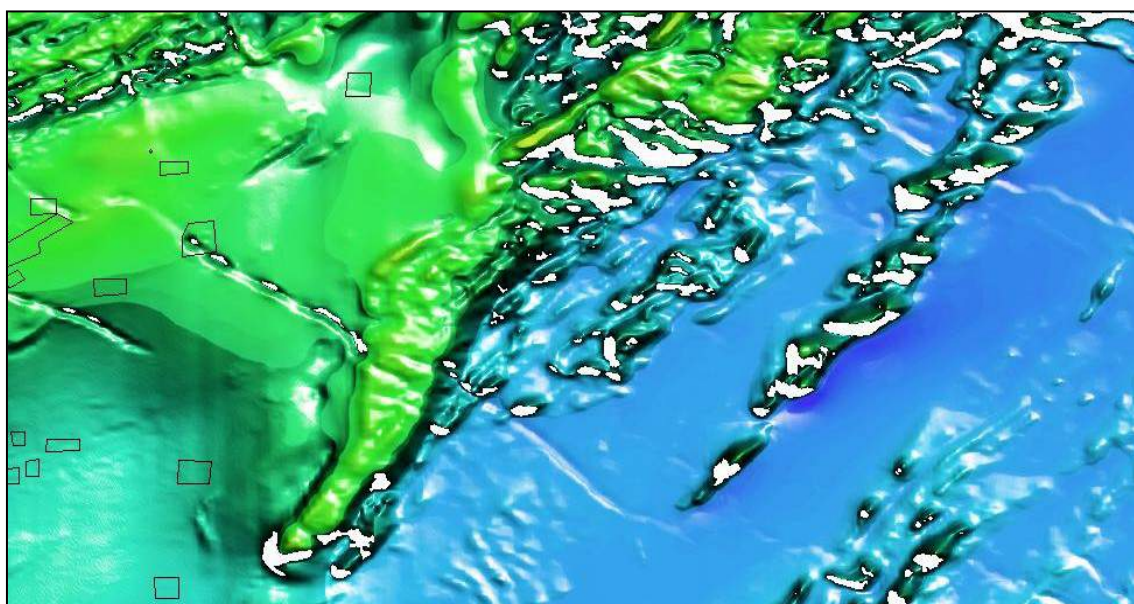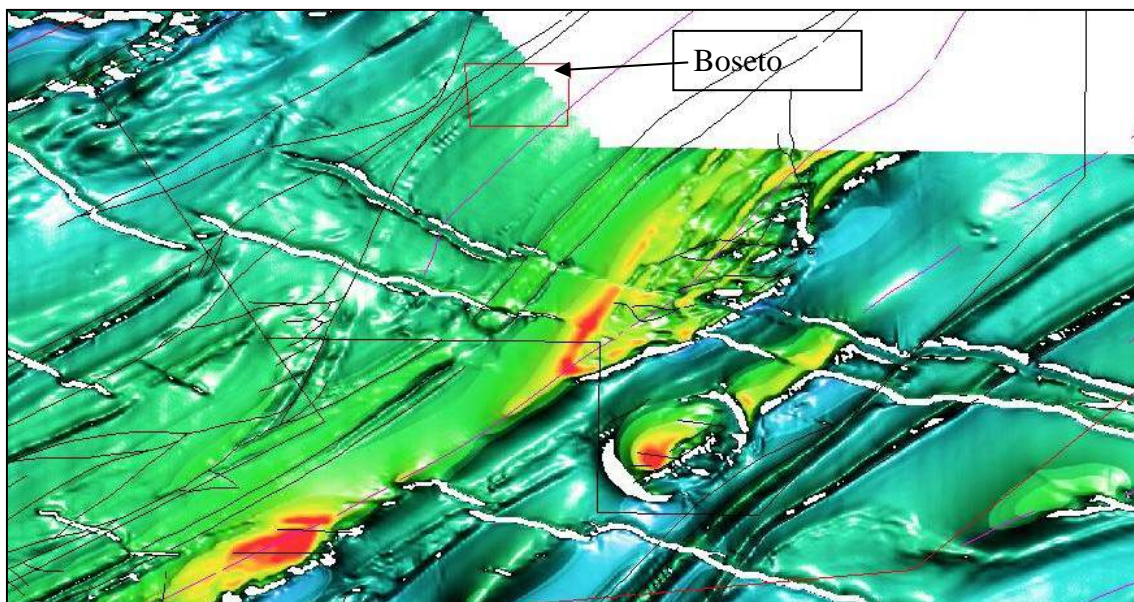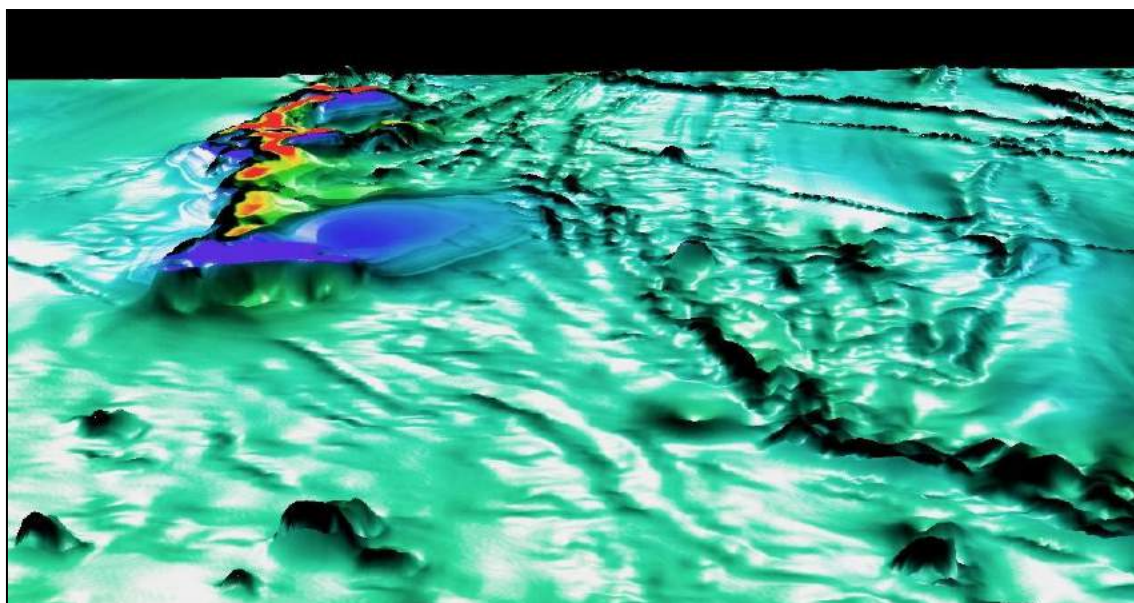
Figure 6 A-D. Terrain views of structure enhanced aeromagnetic data in IMAGINE Virtual GIS® (inserts E and D, figure 4). Also shown are terrain views with an RGB drape generated in Spatial Analyst (ArcView®) in E (insert D) and F (insert G).
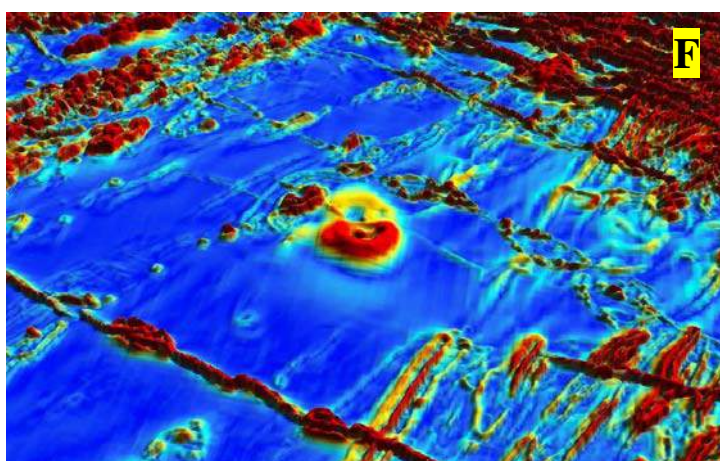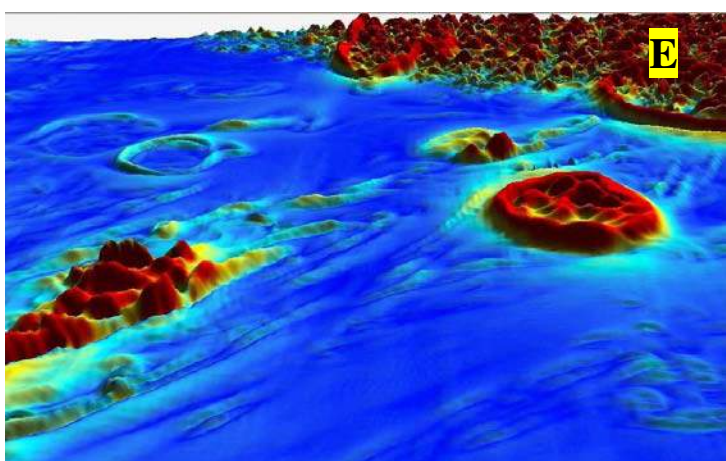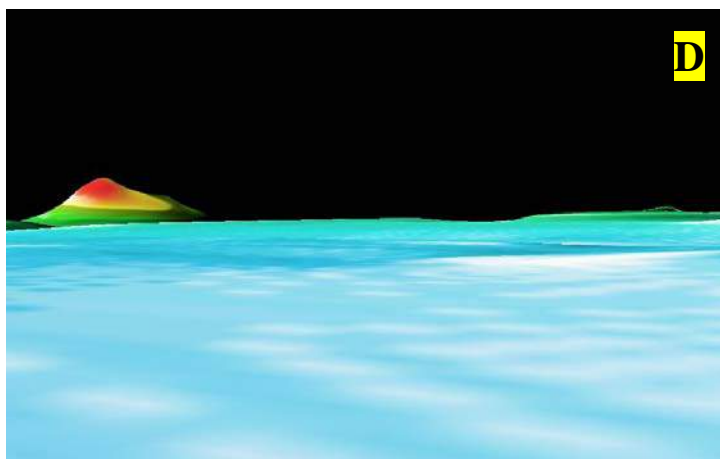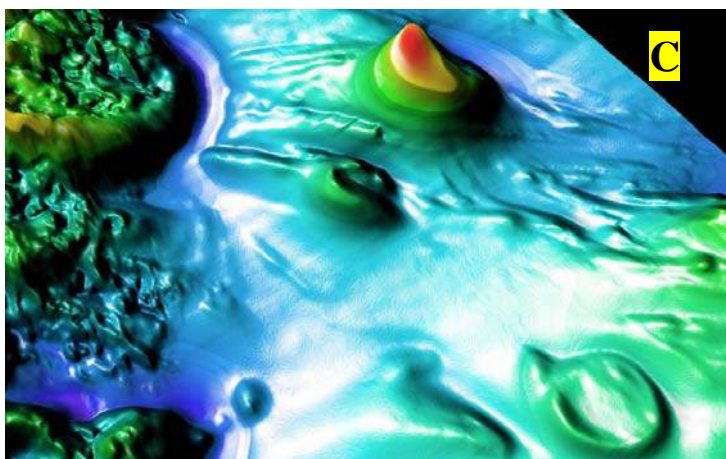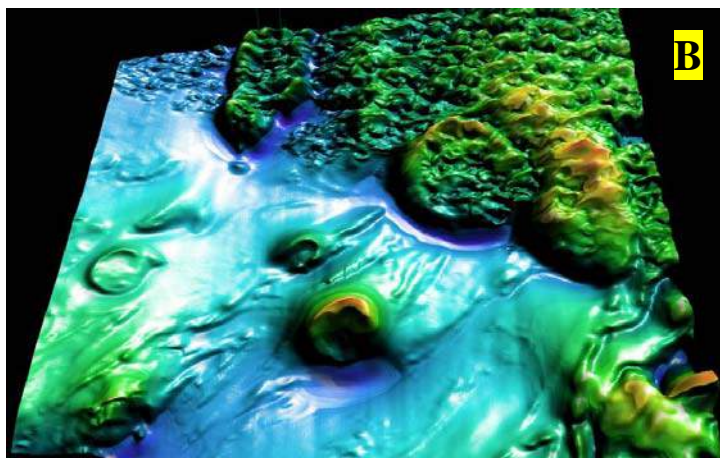
Figure 7. Positional views in IMAGINE Virtual GIS® of the the MABE anomaly in the Tsodilo Hills area with extruded fault planes (A) and drill holes (B). Also shown are images of the Matchless Amphibolite Belt (MAB) extruded onto the regional structurally enhanced aeromagnetic data (C), bouger anomaly gravity data (D) and RTP-TMI aeromagnetic data (E).
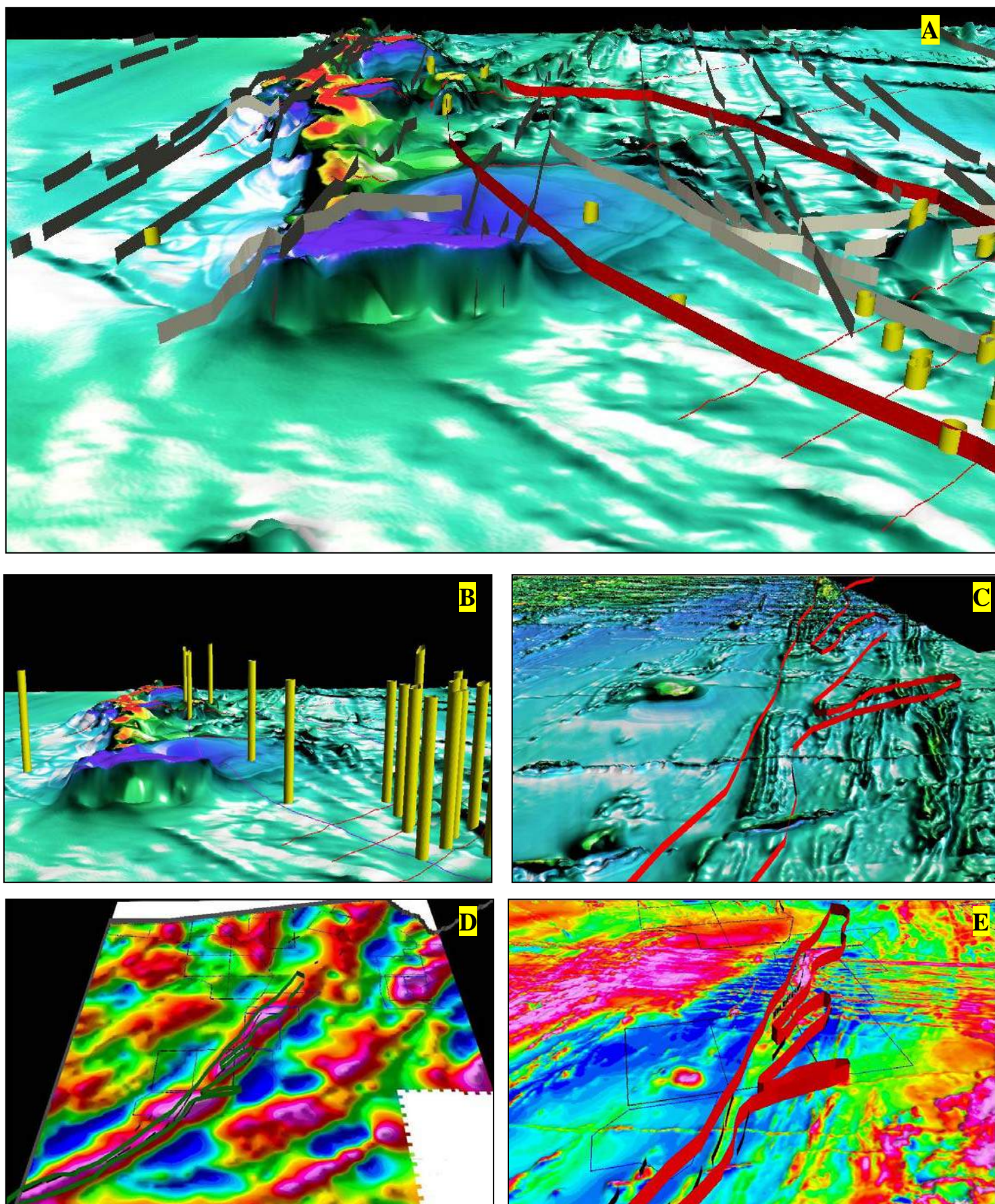
Figure 8. Examples of the utility of integrating various datasets within ArcMap GIS (ArcView®) for regional base metal exploration. (A-D): Tracing the MABE from Namibia into Botswana and the application of buffering, (E): overlaying current data onto previous studies (E) and (F-H): for defining new prospecting licenses (F) VTEM survey (G) and drill targets (H).
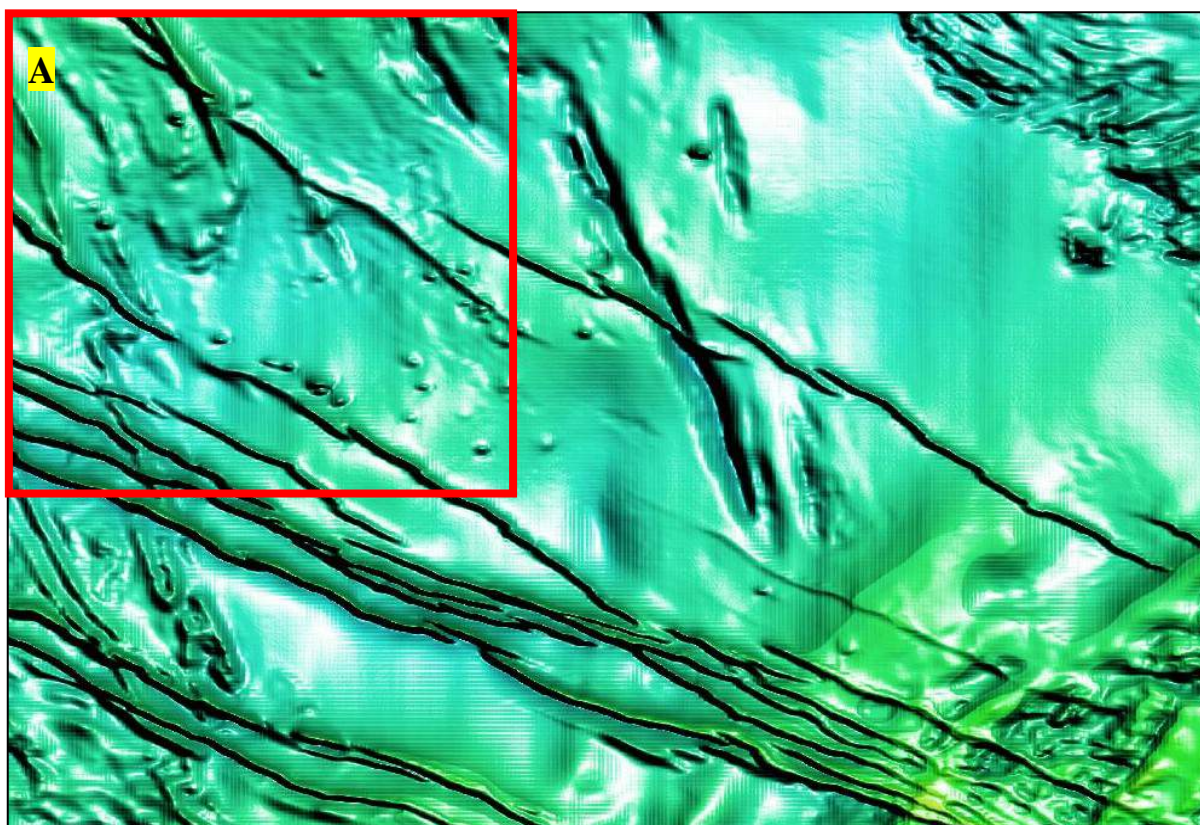
Figure 9. The Nxau Nxau kimberlite field shown with the total horizontal gradient as the DTM overlain by the structurally enhanced aeromagnetic data. The data processed in ER Mapper® using a single grid (A) is shown relative to the data processed as part of a regional mosaic dataset (B) (insert F, figure 4).
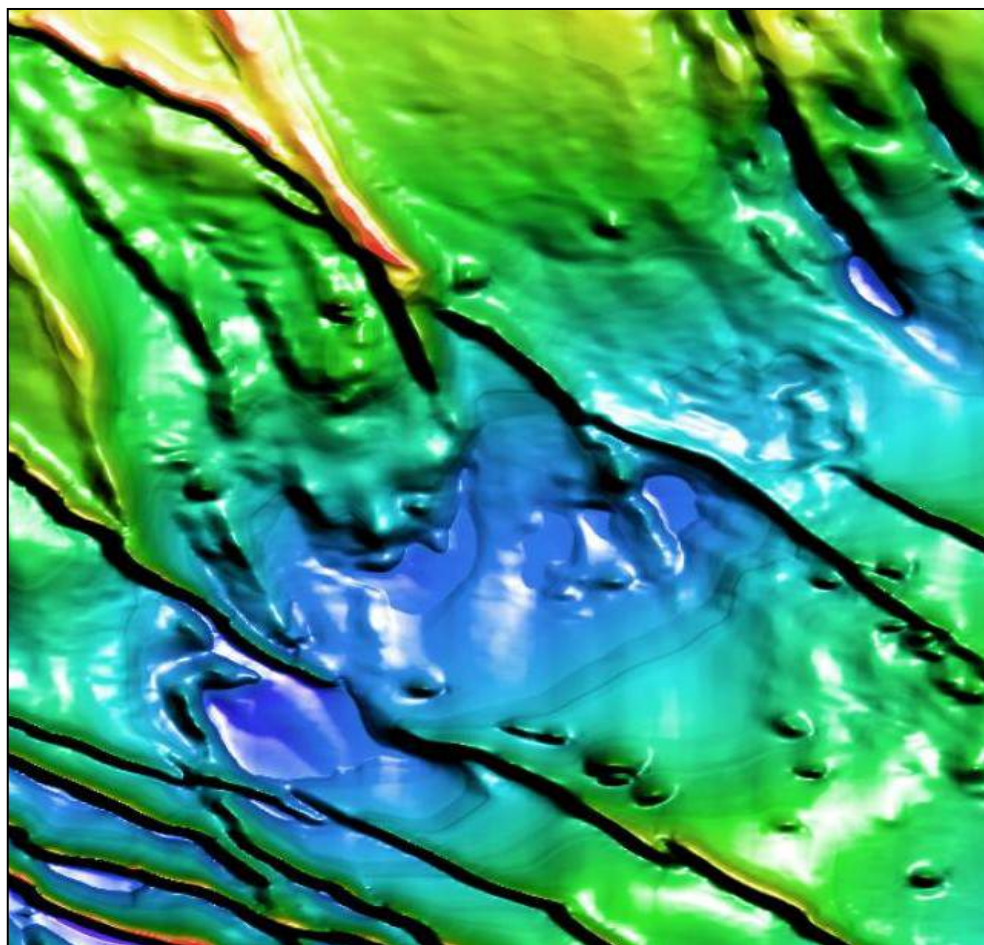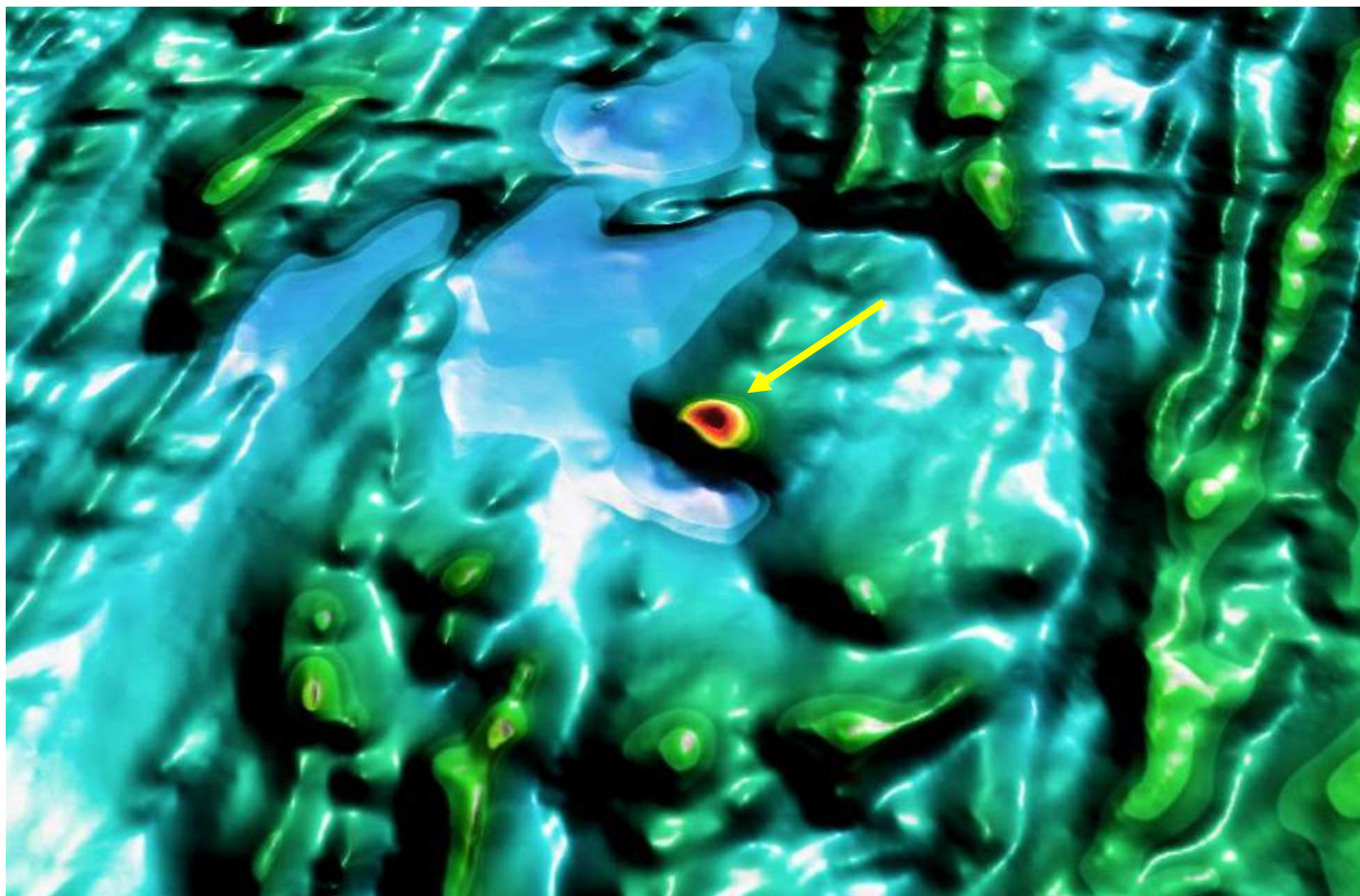
Figure 10. Positional view (A) and terrain view (B) of possible impact crater in IMAGINE Virtual GIS®. The dimple at the centre of the radial feature is prominent in the terrain view and a typical characteristic of impact craters (insert H, figure 4).

Appendix Table 1 Convolution filters and Geoprocessing tools available in ERDAS® Image Interpreter and ER Mapper® respectively.

	ERDAS®	ER Mapper®
Filter		
3x3	cross edge detection	Upward Continuation Half
3x3	edge detect	Upward Continuation One
7x7	edge detect	Upward Continuation Two
3x3	edge enhance	Downward Continuation Half
5x5	edge enhance	Downward Continuation One
7x7	edge enhance	Downward Continuation Two
5x5	haze reduction	1VD
3x3	haze reduction	2VD
3x3	high pass	Automatic Gain Control 3x3
5x5	high pass	Automatic Gain Control 5x5
7x7	high pass	Automatic Gain Control 7x7
3x3	horizontal	Automatic Gain Control 9x9
5x5	horizontal	Horizontal Cubic Fit
7x7	horizontal	Vertical Cubic Fit
3x3	horizontal ED	NE Cubic Fit
3x3	laplacian ED	NW Cubic Fit
3x3	left diagonal ED	Analytical Signal
5x5	low pass	
7x7	low pass	
9x9	low pass	
11x11	low pass	
3x3	low pass	
3x3	right diagonal ED	
3x3	sharpen	
3x3	sharpen2	
3x3	sharpen3	
3x3	sharpen4	
3x3	sharpen5	
3x3	summary	
5x5	summary	
7x7	summary	
3x3	vertical	
7x7	vertical	
5x5	vertical	
3x3	vertical ED	
5	vertical linear smoothing	