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# Geological Interpretation of the 2004 Marrtown Aeromagnetic Survey, Southeastern New Brunswick

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## Sheet 5: Interpretive Notes Part 2

Another group of circular anomalies occurs in the area of the McCully gas field in the east-central part of the Marrtown survey area near Sussex (Fig.13). The anomalies are enhanced on a 1st vertical gradient map (Fig. 15). Compared to the circular anomalies in the northwestern corner of the area, the McCully anomalies have very much smaller amplitudes, most being <6 nT, with two larger ones attaining 11 and 14 nT. One exceptionally large anomaly (180 nT) is probably related to infrastructure linked to the potash industry. Diameters of anomalies are also generally significantly smaller, ranging generally from about 270 to 600 m. Interest in the gas field for hydrocarbons and potash has resulted in considerable drilling, an activity reflected in the many boreholes in the area recorded in the New Brunswick Natural Resources, Minerals, Policy and Planning Division borehole database, compared to the number in the northwestern area. Boreholes from this database are plotted as open circles in Figure 15, and several coincide with circular anomalies, suggesting that most circular anomalies in this area are related to metal casings left in boreholes. Examination of videotape of the ground surface recorded during the aeromagnetic survey, where it passed over four of the anomalies, did not detect any cultural features that could explain the anomalies. Thin snow cover may have hidden any surface expression of drill-holes, though two anomalies coincided with wooded areas that appeared to be undisturbed by any heavy machinery required for drilling. Further investigation of these anomalies is required to obtain an unequivocal solution regarding their source.

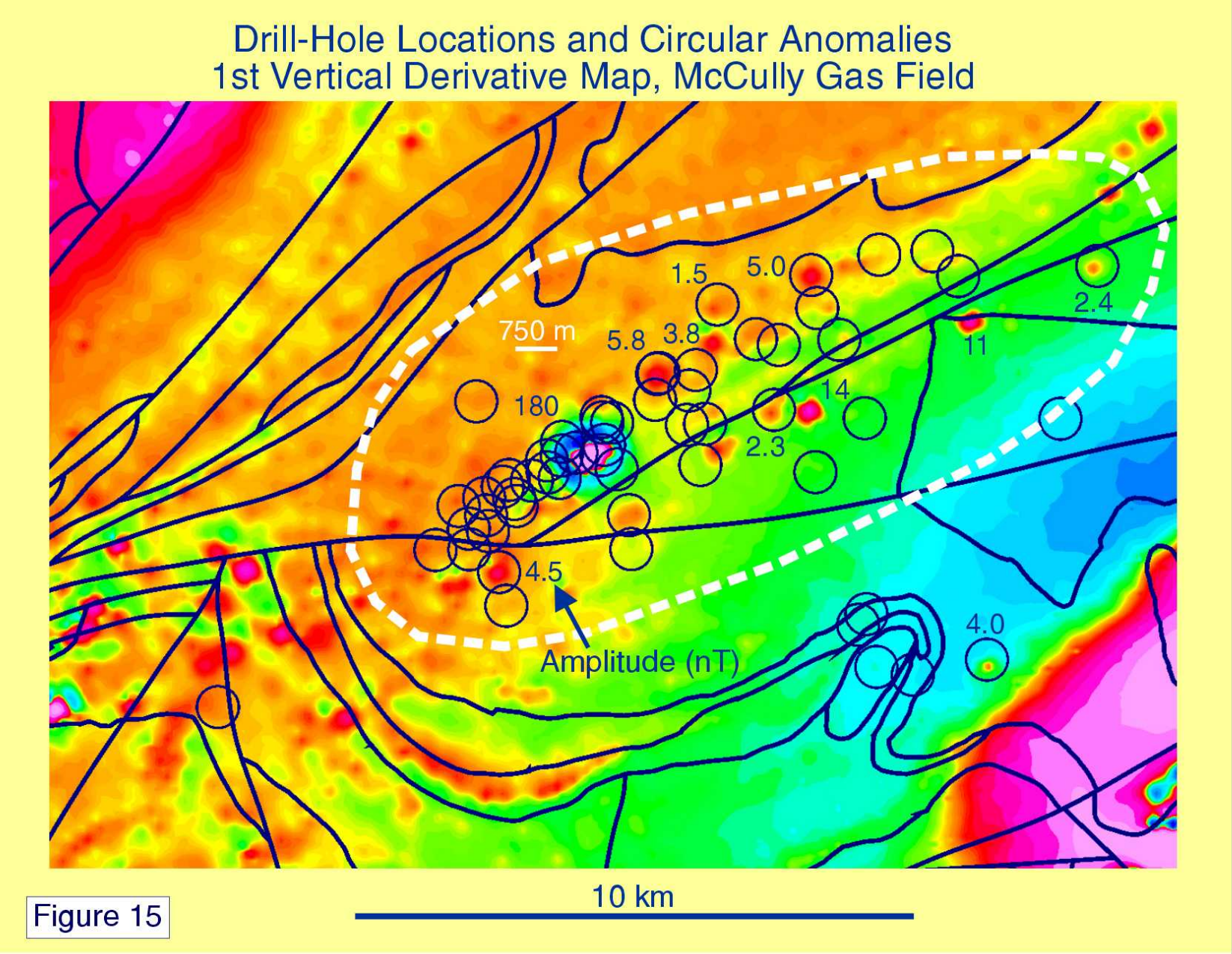
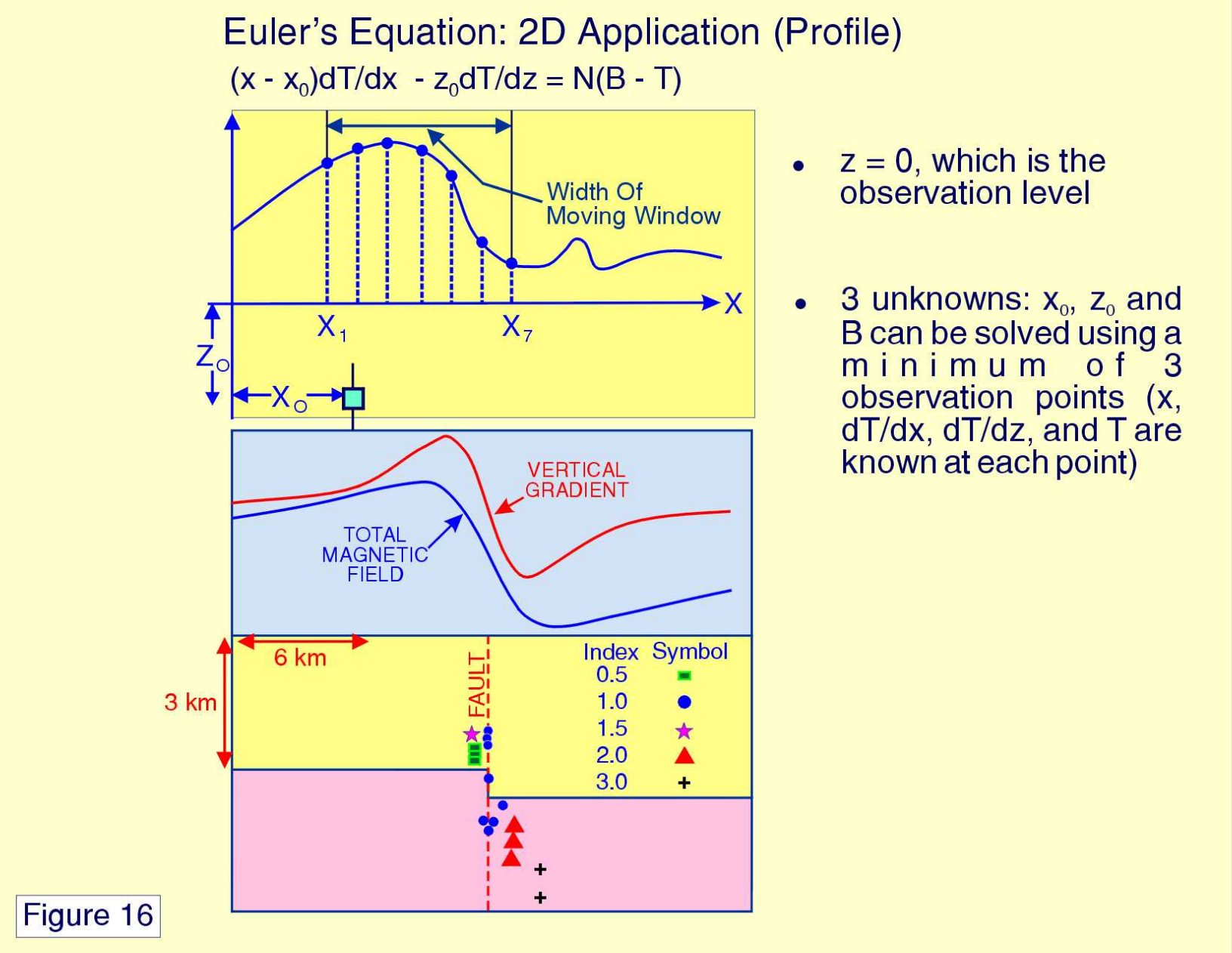

Drill-Hole Locations and Circular Anomalies
1st Vertical Derivative Map, McCully Gas Field

Figure 15

Carboniferous sedimentary rocks resting on Lower Palaeozoic/Neoproterozoic basement cover most of the survey area. Knowledge of depth to basement is important for resource exploration both within the Carboniferous cover and the basement. Data archived in the New Brunswick Natural Resources, Minerals, Policy and Planning Division borehole database provide limited and irregularly distributed information on depth to basement. The new magnetic data afford a means for estimating many depths, more regularly distributed throughout the area, using gradients of the magnetic field. A popular method for automatically estimating basement depth is Euler deconvolution (Reid et al., 1990), based on Euler's homogeneous equation, which for data distributed over a map is:

- $(x - x_0)dT/dx + (y - y_0)dT/dy + (z - z_0)dT/dz = N(B-T)$
- $(x_0,y_0,z_0)$ is the position of a source, whose total field, T, is detected at (x,y,z),
- B is the regional field; N is the structural index, which depends on the type of the source,
- dT/dx, dT/dy and dT/dz are the two horizontal gradients and the vertical gradient.

The value of N is indicative of source geometry, controlling the rate of decrease of the field as distance to source changes, hence it is important to use a value that represents the prevailing geometry of geological features in an area. If the geometry is unknown, different values for N should be applied. An example of Euler application for a magnetic profile crossing a vertical fault is shown in Figure 16. Structural indices ranging from 0.5 to 3.0 were used. The best estimates were obtained for indices of 1 and 0.5.


Euler's Equation: 2D Application (Profile)

$(x - x_0)dT/dx - z_0dT/dz = N(B - T)$

- z = 0, which is the observation level
- 3 unknowns: $x_0$, $z_0$ and B can be solved using a minimum of 3 observation points (x, dT/dx, dT/dz, and T are known at each point)

Figure 16

Locations of drill-holes for the Marrtown survey area listed in the New Brunswick Natural Resources, Minerals, Policy and Planning Division borehole database, and of Euler depths to magnetic sources are plotted in Figure 17 (a and b, respectively). The drill-hole depths (metres) represent depths to the end of the holes. Depths to Pre-Carboniferous basement, recorded in a few holes, are posted in Figure 17a. Corresponding holes are plotted as solid red squares in Figure 17b for cross-reference. Euler depths do not necessarily coincide with Pre-Carboniferous basement, because the weakly magnetic Carboniferous cover may be underlain by older weakly magnetic rocks, and estimated depths to magnetic sources could be well below the Carboniferous. The Euler application is complicated by uncertainty in selecting a structural index, as discussed previously, and by the width of the moving window (Fig. 16). Here, results of using a structural index of 0.5 together with widths of 1500 m, 3000 m and 6000 m are plotted. The automatic process generates many thousands of overlapping solutions, (Fig. 17b). On a first order basis, the Euler solutions appear to be reasonable. Solutions located on Carboniferous cover range up to 2735 m, whereas the deepest borehole in Carboniferous rocks is 3260 m. Also, for the shallower estimates, the northwest trending dyke north of latitude 46° is picked up by the Euler method returning depths less than 100 m. Obviously, further trial and error study is required to refine the results. More drill-hole information would help constrain such a study; perhaps such information could be forthcoming from industry.

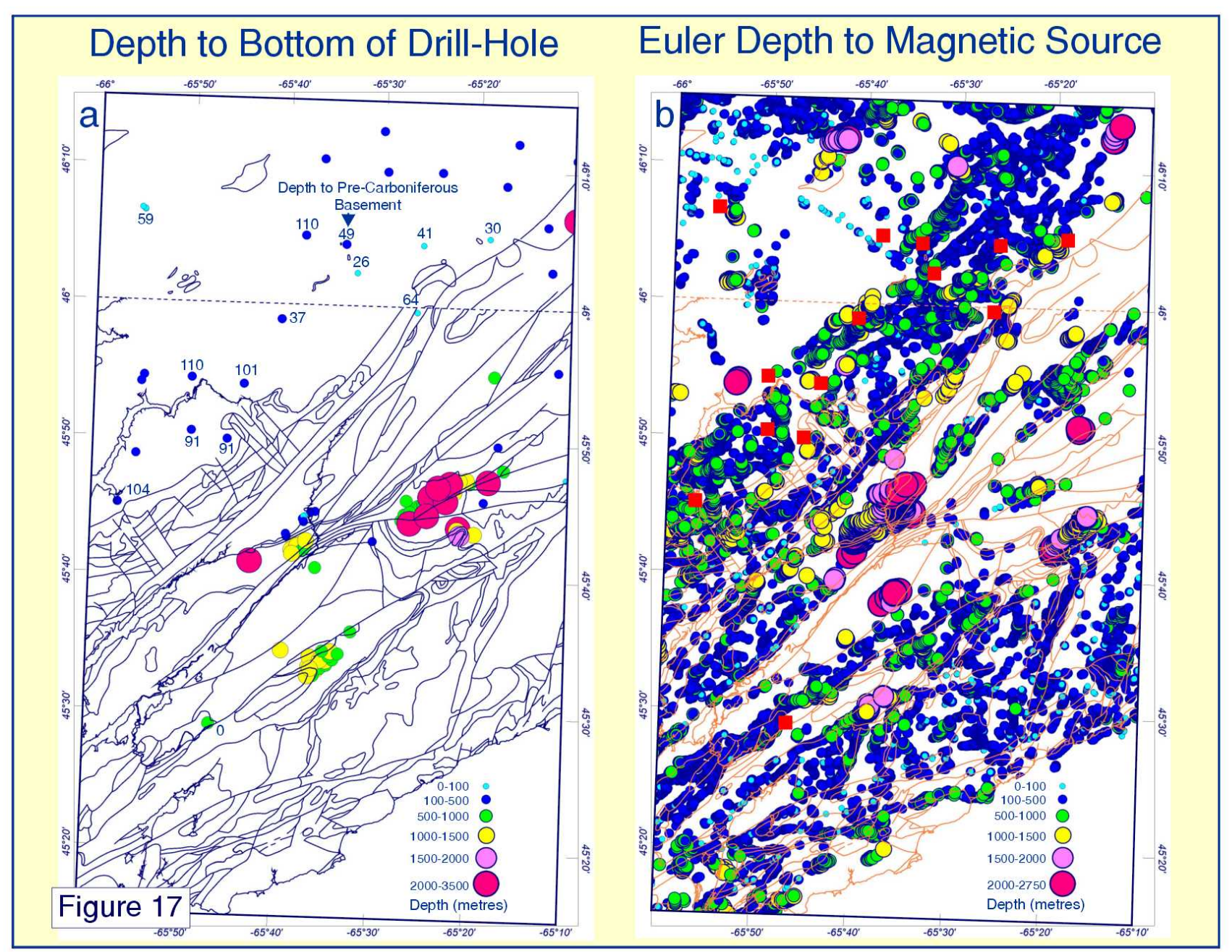

Depth to Bottom of Drill-Hole
Euler Depth to Magnetic Source

Figure 17

A preliminary interpretation of data in the northern part of the Marrtown survey area (Figures 18-22) illustrates the utility of the new aeromagnetic data. Geological contacts (blue lines) and the zero contour (black lines) of the first vertical derivative of the magnetic field are superposed on all figures. Carboniferous sedimentary rocks cover most of the area. Lower Palaeozoic sedimentary and volcanic rocks are mapped near its southern boundary, and small developments (coloured areas) of Late Mississippian volcanic rocks (B,F), Pre-Carboniferous sedimentary rocks (PC) and Devonian granitoids (D) occur in its northern half. More details of the geology are provided on Sheets 1, 2 or 3. The zero contour of the first vertical derivative is used as a guide for mapping contacts between units having contrasting magnetizations. This approach was used to map sub-Carboniferous belts of mainly Ordovician-Silurian volcanic and sedimentary rocks (OSVAS), interpreted on the basis of positive magnetic signatures. A perturbed field in the northwest corner is attributed to Late Mississippian basalts. Probable shallow igneous plugs (possible feeders) and a small felsic igneous complex are interpreted in the same area, the latter by comparing its signature with that of a mapped felsic complex to the south. A contact, C2, running northeast across Pennsylvanian cover rocks is discussed in more detail with respect to the derivative maps. Large sub-Carboniferous felsic and mafic/felsic igneous complexes bounded partly by contacts C3 and C4, respectively, are based on linear/curvilinear magnetic highs and a negative and positive gravity anomaly, respectively.

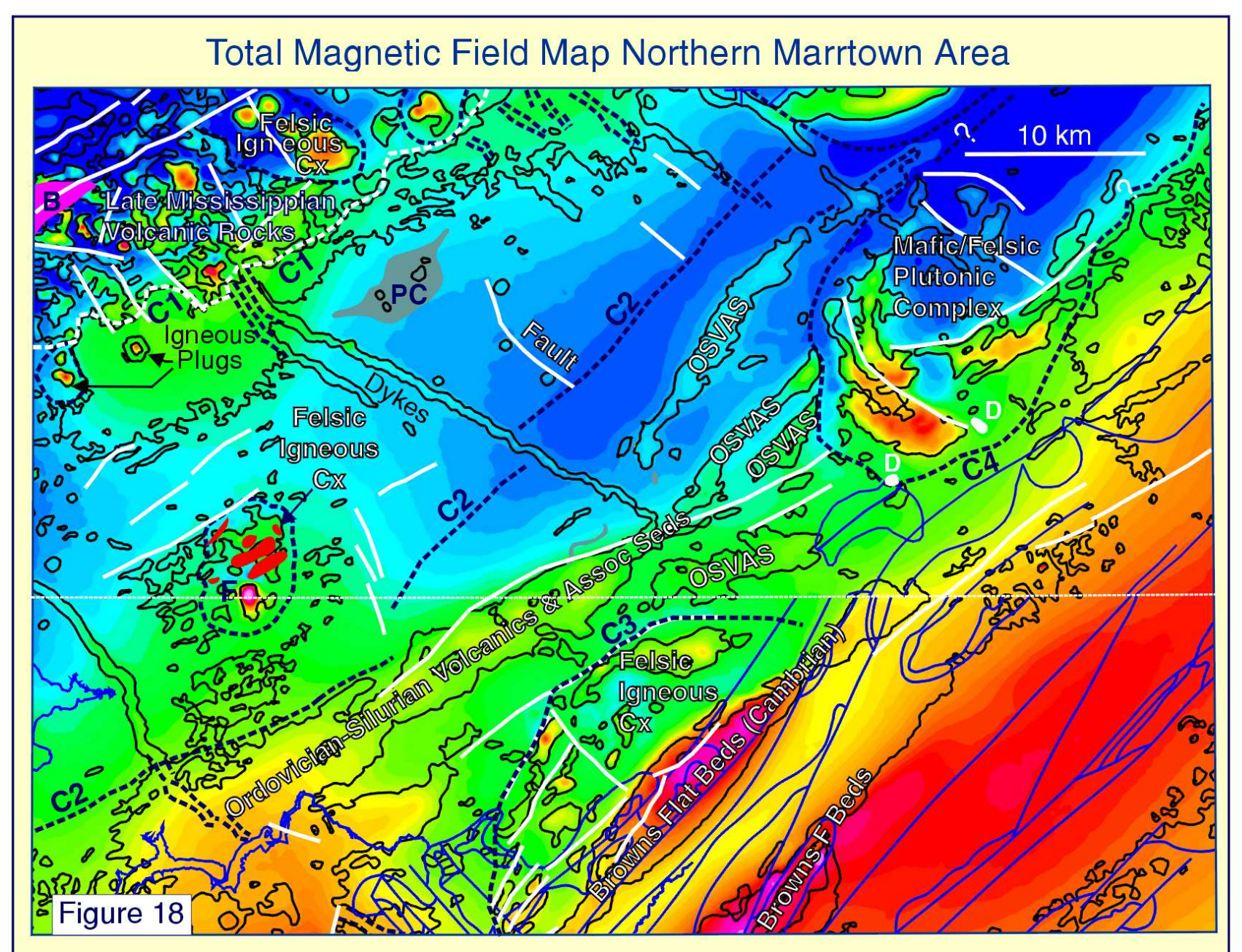

Total Magnetic Field Map Northern Marrtown Area

Figure 18

An image of the 1st vertical derivative of the Bouguer gravity anomaly is displayed in Figure 19. It demonstrates the value of complementary geophysical data sets in the geological interpretation of geophysical data. The image reflects variations in crustal density, which have particular relevance with respect to the presence of intrusive rocks such as granite or gabbro. These rock types typically produce negative or positive gravity anomalies, respectively. Figure 19 displays several prominent negative anomalies having the oval shape so characteristic of the shape of granitic plutons. One large anomaly underlies the northwestern corner of the area, where basaltic rocks have been mapped, and where their more extensive distribution along with the presence of igneous plugs and a felsic igneous complex have been interpreted on the basis of magnetic data. An underlying pluton could be the source of the observed/proposed igneous activity. Another granitic pluton is proposed under a felsic igneous complex bounded by contact C3 and a belt of Browns Flat Beds in the south central part of the area, where another distinct negative gravity anomaly is present. Northeast of this complex a mafic/felsic igneous complex (bounded by contact C4) is proposed on the evidence of arcuate magnetic highs, which define a large oval complex, and the presence of a gravity high, which signifies a considerable presence of underlying basic igneous rocks. On the other hand, two small occurrences of Devonian granitoids in the area suggest an underlying granitic complex. Possibly the complex includes granitic components, but mafic components are considered to be predominant.

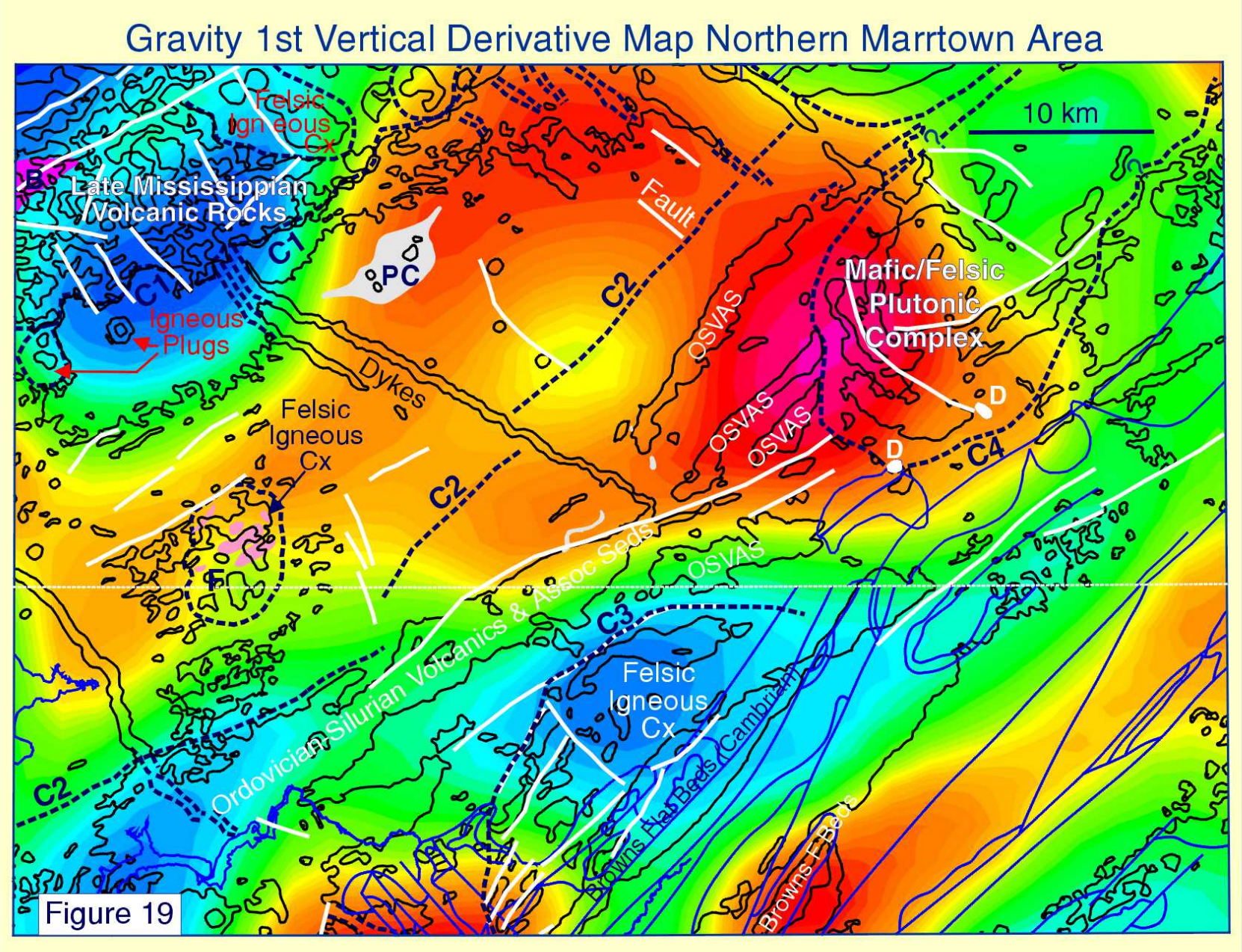

Gravity 1st Vertical Derivative Map Northern Marrtown Area

Figure 19

An effective image for geological interpretation is the 1st vertical derivative image (Fig. 20), which displays four broad belts of different magnetic pattern, running southwest-northeast across the area. The patterns of the two belts over Carboniferous sedimentary rocks are very similar, presenting a "stippled' texture of magnetic features, probably reflecting subtle variations in magnetization within these rocks. Between them is a belt characterized by extensive linear and curvilinear magnetic highs, which provide the principal evidence for proposed felsic and mafic/felsic igneous complexes, and zones of Ordovician-Silurian volcanic and sedimentary rocks within the belt. Anomalies defining the mafic/felsic igneous complex apparently truncate anomalies related to the volcanic-sedimentary rocks. This and the arcuate nature of anomalies within the complex suggest an intrusive relationship. The magnetic pattern of the belt in the northwest corner is distinct from other patterns in the area, comprising circular or short, irregular linear positive anomalies having no apparent preferred orientation. It is attributed to Late Mississippian volcanic rocks, mapped locally and which probably underlie most of this belt. The belt is separated from the adjacent "stippled" belt to the southeast by the interpreted contact C1. Within the latter belt narrow linear magnetic highs, some very extensive, map clearly the paths of diabase dykes, and contact C2 marks a change in level of the 1st vertical derivative, and a possible subtle change in orientation of anomalies. No geological feature is mapped along this trend (St. Peter, 1997), so it may represent a weak expression of a fault.

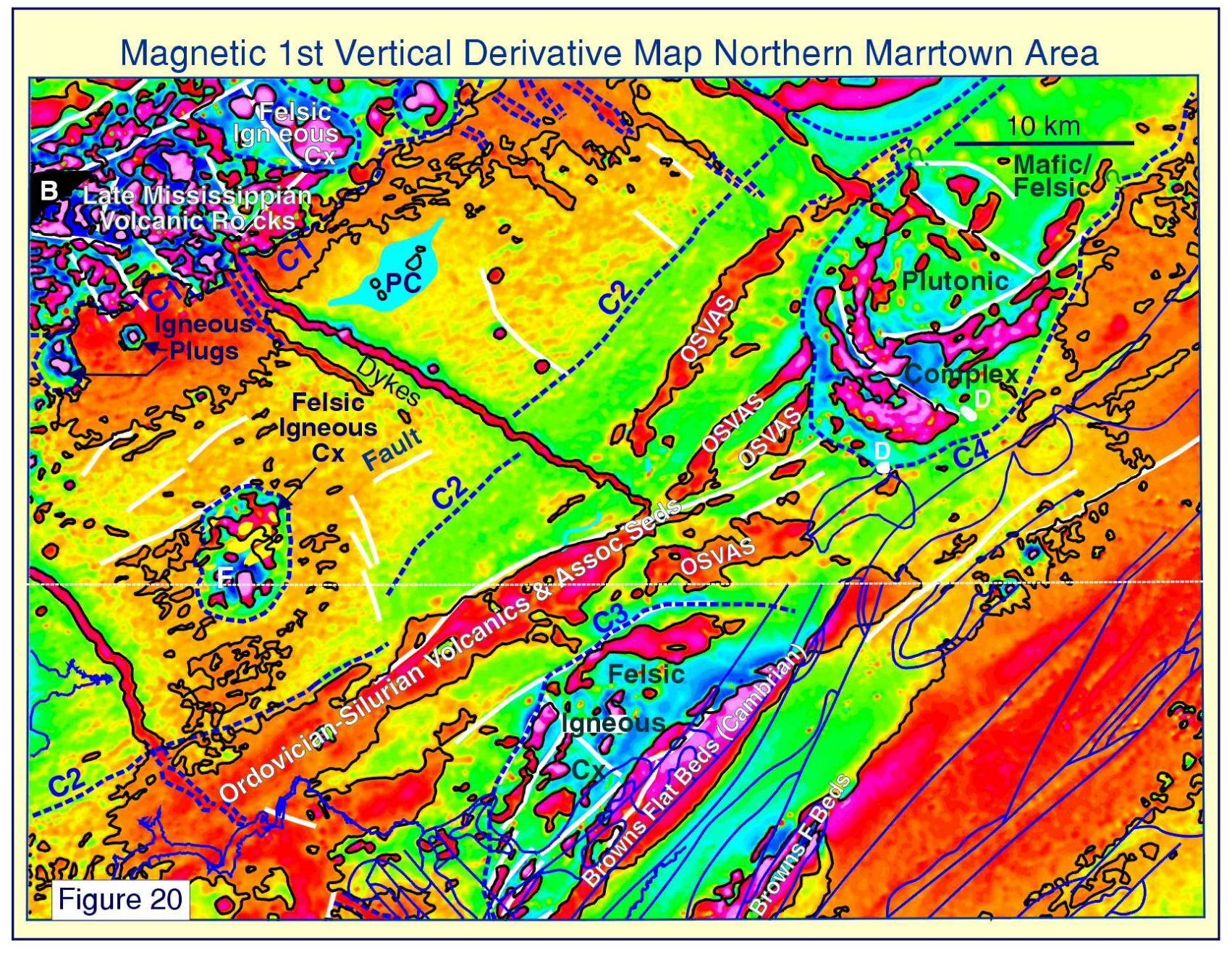

Magnetic 1st Vertical Derivative Map Northern Marrtown Area

Figure 20

The image of the 2nd vertical derivative of the magnetic field, like its 1st derivative counterpart, clearly distinguishes four first order belts of magnetic pattern. Likewise, second order features within each of these belts are very similar to those of the 1st vertical derivative image. A major difference is the increase in detail within the belts coinciding with Carboniferous sedimentary rocks. Here, fine features of the magnetic field, which may be considered as third order features, are brought into focus, thereby enhancing the internal structural fabric of the belts. The 2nd derivative map also provides a finer picture of structural fabric within the broad central belt, proposed to be underlain by Ordovician-Silurian volcanic and sedimentary rocks, and two large igneous complexes. The ages of these complexes are probably post-Silurian, based on the clear truncation of anomaly trends attributed to Ordovician-Silurian assemblages and the occurrence of Devonian granitoids at surface in the area of the proposed mafic/felsic igneous complex. With enhanced third order features visible in all belts, the case for establishing the contact C2 is strengthened, particularly northeast of the extensive central dyke, where trends northwest of C2 apparently are oriented principally east-northeast, whereas to the southeast there are in addition northeast trends. As mentioned with respect to Figure 20 no geological feature has been mapped along the C2 trend, so its nature remains enigmatic, and its validity questionable. A fine northwest-southeast grain imposed on the 2nd vertical derivative fabric is a processing artifact related to the high resolution of data along the flight-lines.

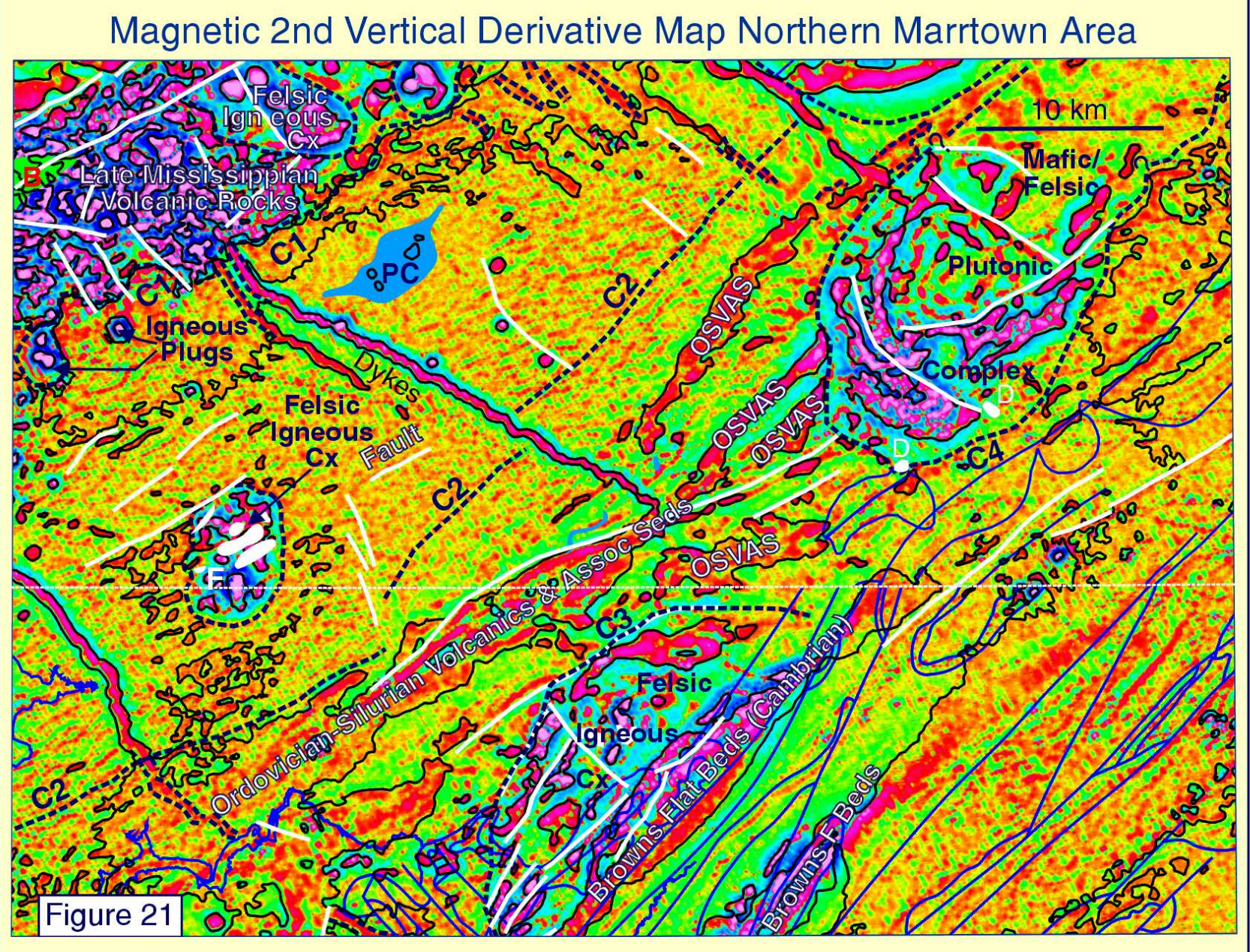

Magnetic 2nd Vertical Derivative Map Northern Marrtown Area

Figure 21

A schematic interpretive geology map of the northern part of the Marrtown survey area is portrayed in Figure 22, together with geology defined by conventional geological mapping. The geophysical interpretation contributes significantly to an understanding of the geology, particularly with regard to:

- the surface or near-surface distribution of Late Mississippian volcanic rocks,
- the locations of dykes, which are probably related to the Late Mississippian igneous activity,
- locations of possible igneous plugs,
- sub-Carboniferous geology in a broad belt trending northeast-southwest across the central part of the area, where Ordovician-Silurian volcanic-sedimentary rocks are proposed to form much of the sub-Carboniferous basement, and where large post-Silurian igneous complexes are present,
- previously unmapped faults.

The proposed faults are based mainly on magnetic patterns on the 1st and 2nd vertical derivative images. This summary map displays also the zero contour (black lines) of the 1st vertical derivative map, which was instrumental in delineating magnetic Ordovician-Silurian assemblages, and the contact between mainly Late Mississippian volcanic rocks in the northwest corner of the area and adjacent mainly Pennsylvanian sedimentary rocks. Many zero value contours have not been associated with any geological contacts, and these may simply fall within a small noise envelope and have no geological significance. The zero value is a parameter that should be used judiciously.

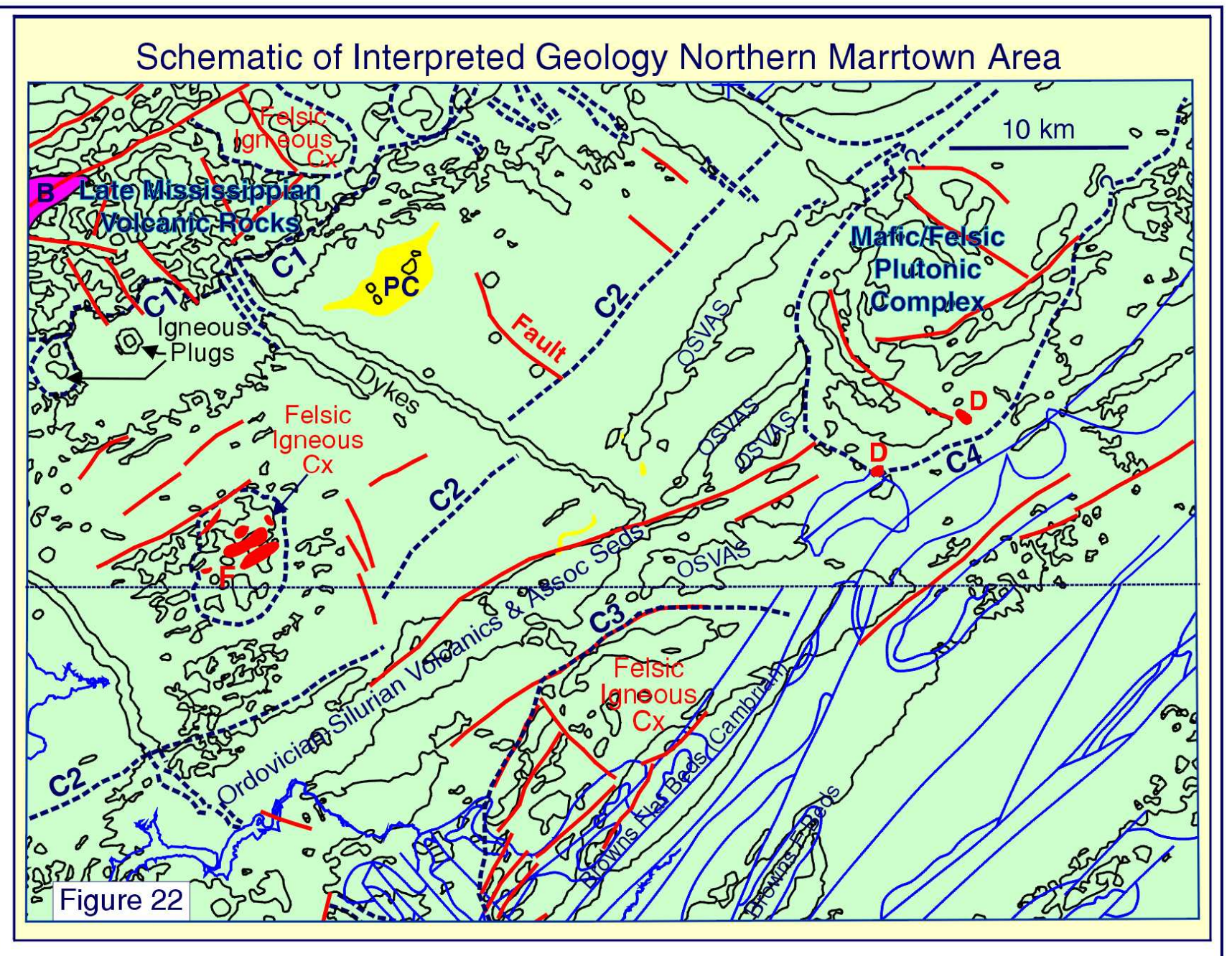

Schematic of Interpreted Geology Northern Marrtown Area

Figure 22

The virtues of the 2nd vertical derivative for distinguishing subtle variations in the magnetic field have been outlined and illustrated with respect to Figure 4 (Sheet 4), and this attribute is used to examine Carboniferous sedimentary rocks in the Sussex-Petitcodiac area. Carboniferous sedimentary rocks in this part of New Brunswick are weakly magnetic (King and Barr, 2003b), having quite low magnetic susceptibilities ranging from 0.10 – 0.23 x $10^{-3}$ SI (Fig. 6). Nevertheless, the associated patterns of the 2nd vertical derivative indicate that they are imaged in the magnetic field. Knowledge of magnetic susceptibilities for Carboniferous sedimentary rocks is based on a very small sample of ten measurements (King and Barr, 2003b). This lack of knowledge of magnetic properties of these rocks is a shortcoming that needs to be addressed in any subsequent comprehensive magnetic interpretive study. In Figure 23 geological contacts and faults interpreted principally on the basis of the 2nd vertical derivative image, but also using the 1st vertical derivative image are superposed on the latter image. There are several correlations between contacts and bands of more intense 1st vertical derivative. There are also several contacts defining narrow linear units, which have little or no expression in the 1st vertical derivative image. The interpretation of contacts has not been applied to all of the area, but is restricted largely to areas covered by Carboniferous sedimentary rocks, hence no contacts are displayed for the northwestern or southeastern corners of the area.

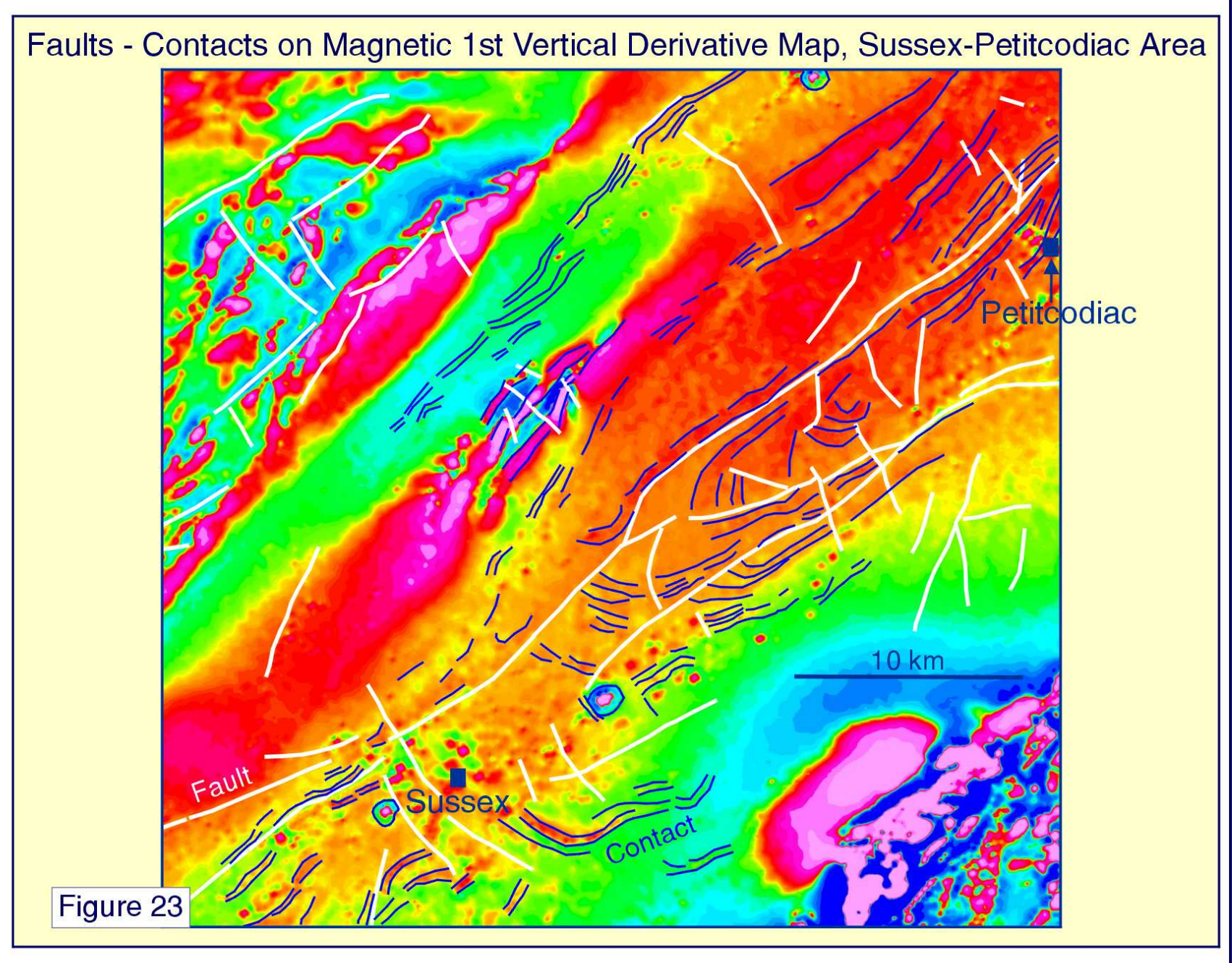

Faults - Contacts on Magnetic 1st Vertical Derivative Map, Sussex-Petitcodiac Area

Figure 23

The power of the 2nd vertical derivative image may be appreciated by examining Figure 24, on which the same interpreted contacts and faults of Figure 23 are superposed. Here the correlation between contacts and positive features is more easily discerned than on the 1st vertical derivative image. The northwest-southeast linear grain imposed on the image during processing (see discussion of Figure 21) presents noisy background interference, but does not seriously impede interpretation. Perhaps the only thing to be cautious about is interpretation of faults having a northwest trend, since some features that suggest a fault are artifacts related to the northwest-southeast flight-line orientation. As mentioned in previous figure descriptions, the 2nd vertical derivative image has a "stippled" appearance. This is again an artifact of processing related to the fact that along the lines data resolution is much higher, being measured in metres, whereas the flight-line spacing is 300 m. Consequently, very short wavelength anomalies along a flight-line, which may not extend to adjacent flight-lines, become even more isolated during the process of generating derivative maps, producing a "stippled" appearance. It is possible with judicious filtering of the data to improve the appearance of the 2nd vertical derivative image, possibly enhancing continuity of features between flight-lines, and extracting further geological information from the data. This step has not been pursued in this preliminary study.

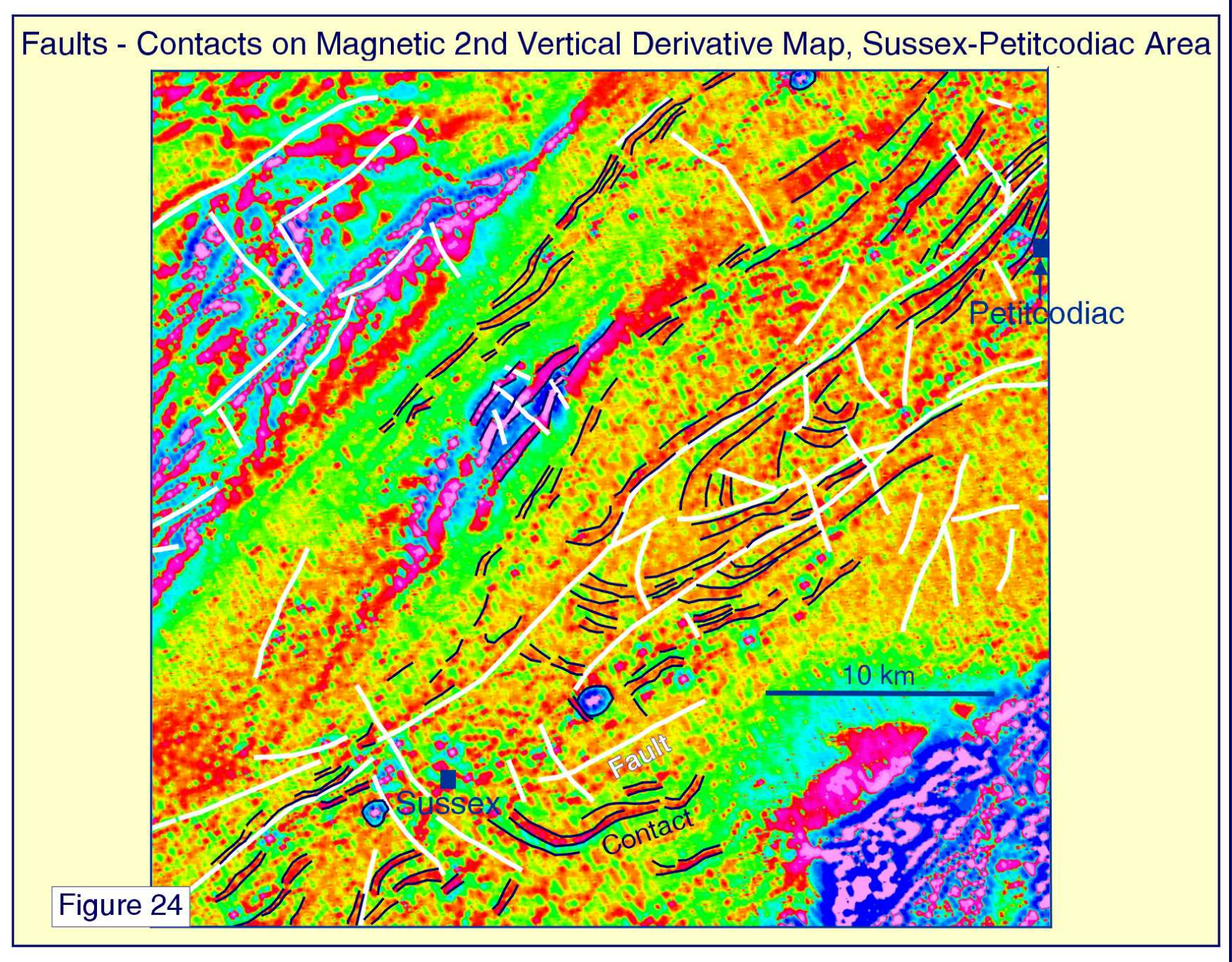

Faults - Contacts on Magnetic 2nd Vertical Derivative Map, Sussex-Petitcodiac Area

Figure 24

The faults and contacts interpreted in the Carboniferous sedimentary rocks of the Sussex-Petitcodiac area are superposed on a shaded total magnetic field image in Figure 25. This figure is included to illustrate the requirement to use derivative maps in cases where the total field apparently is quite featureless. Practically none of the contacts and possibly only one or two faults would have been interpreted on the basis of this image. The message is that all types of map should be used in a magnetic interpretation, since they each bring a certain utility to interpretation of the data.

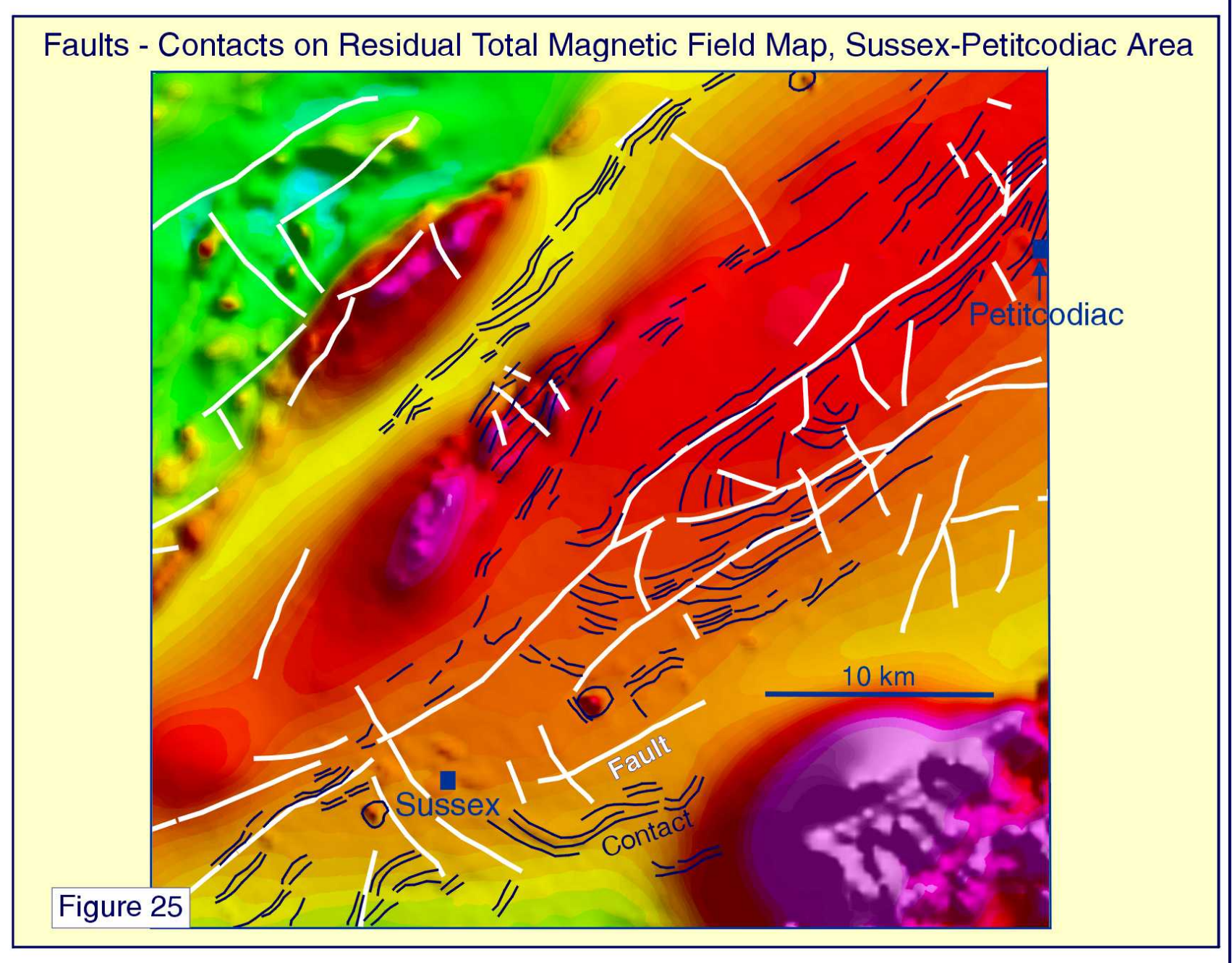

Faults - Contacts on Residual Total Magnetic Field Map, Sussex-Petitcodiac Area

Figure 25

A comparison of geologically mapped contacts and faults in the Sussex-Petitcodiac area with those derived from magnetic interpretation is presented in Figure 26. The geological information is extracted from four 1:50,000 scale compilations that cover the area. Parts of each of these maps fall in the areas designated as a, b, c and d, which have been compiled, respectively, by McLeod and Johnson (1999a,b,c,d). In area d good correspondence between geologically mapped and geophysically derived contacts testifies to the validity of the magnetic interpretations, and adds a measure of confidence to the feasibility of other contacts interpreted from the magnetic data. The interpreted contacts and faults provide valuable insight into both structure and stratigraphy of the Carboniferous sedimentary succession. Interpretation of magnetic data can make an important contribution to studies of these rocks, and with further processing of the data more refined interpretations are possible.

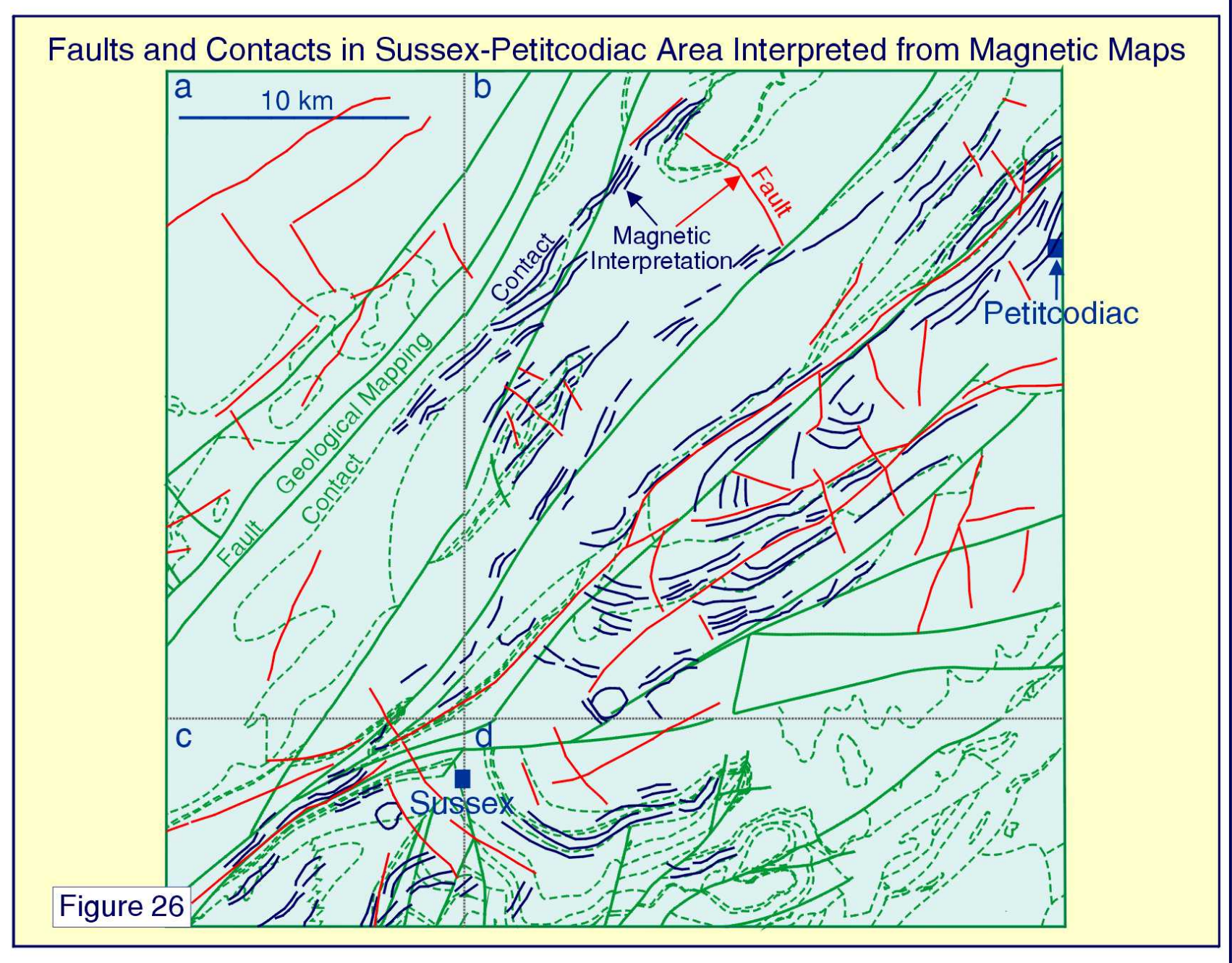

Faults and Contacts in Sussex-Petitcodiac Area Interpreted from Magnetic Maps

Figure 26

## Conclusions

It has been demonstrated that data obtained by the Marrtown high resolution aeromagnetic survey may be applied to several aspects of the geology of the survey area, providing new information on a variety of geological issues. The data have helped enhance geological mapping of exposed Carboniferous sedimentary rocks, exposed Pre-Carboniferous basement and buried Pre-Carboniferous basement. They have provided estimates of depth to Pre-Carboniferous basement and quantitative models of the third dimension. Specifically, they have:

- predicted that Late Mississippian basaltic rocks are more extensive than geological mapping indicates,
- identified diabase dykes and igneous plugs, and outlined large near-surface or shallow igneous complexes,
- outlined Ordovician-Silurian volcanic-sedimentary belts buried beneath Carboniferous cover,
- delineated stratigraphic contacts and faults within the Carboniferous succession,
- provided estimates of depth to Pre-Carboniferous basement,
- identified numerous circular anomalies, some of which are probably linked to metal casings in drill-hole and some of which may be generated by igneous plugs,
- been used to model the third dimension, revealing a crustal section dominated by steep faults and contacts (aside from the sub-horizontal Carboniferous cover rocks) with geological units extending to several kilometres depth.

Study of each one of these topics may be expanded to provide more detailed information than presented in this preliminary appraisal of the data.

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The aeromagnetic survey was flown and processed by Sander Geophysics Limited, Ottawa.

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Minerals, Policy and Planning Division
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