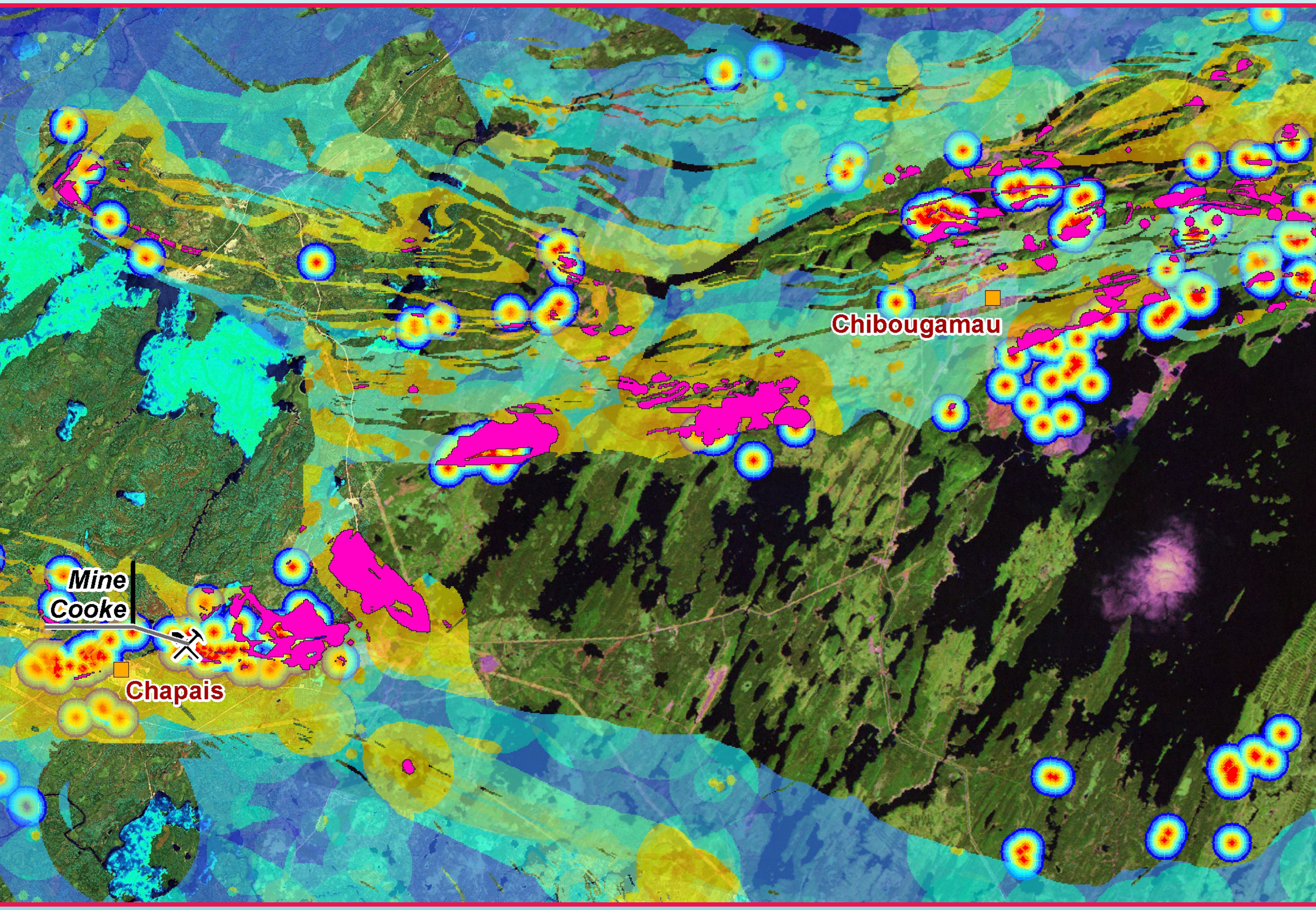
EP 2011-02

Volcanogenic massive sulphide potential in the Abitibi - 2011 version



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Abstract

The mineral potential favourability for volcanogenic massive sulphide (VMS) deposits in the Abitibi was updated in 2011. The work outlined 3,611 high-favourability zones containing more than 365 targets that were unstaked as at April 9, 2011. A favourability map was produced at 1:500,000 scale and favourability zones were entered into GESTIM.

All VMS data modelling for the 2011 version was done using the ModelBuilder tool in ArcGIS 9.3. The process for calculating the Abitibi's VMS potential is now fully programmed and can be automatically executed in just a few hours. The possibility of quickly testing new parameters or different calibration sets represents a significant improvement to the mineral potential assessment process and will be applicable to future metallogenic models developed by the MRNF.

The 2011 data integration uses 22 parameters compared to 26 in the 2005 version. Parameters were weighted using the Weights of Evidence method and a set of 51 VMS mines which were themselves weighted according to productivity. Parameters were then combined using a fuzzy logic approach. Twelve mines excluded from the weighting were used to validate the map's predictive ability.

A minimum favourability threshold was established using a quantile-quantile plot based on the calculated favourabilities for the VMS mines. The threshold, which encompasses 94% of the VMS producers, was then used to create high-favourability zones (HFZs). The unstaked portions of these zones as at April 9, 2011 were designated as targets.

The following digital products are available with this document: 1) the Abitibi VMS mineral potential map in Geotiff, GRD (ESRI), and Google Earth formats; and 2) the HFZs and unstaked targets as at April 9, 2011 in ArcGIS and Google Earth formats. An image combining the mineral potential map and high-favourability zones is also available in GESTIM.

TABLE DES MATIÈRES

INTRODUCTION

Since the 2005 publication of the first mineral potential assessment for the Abitibi, more than 100,000 new rock analyses and all available high-resolution MEGATEM data have been added to SIGÉOM[1]. In addition, some sizeable areas of the Abitibi Subprovince have been mapped and reinterpreted since 2005 (Leclerc and Houle, 2011; Leclerc *et al.*, 2011; Goutier and Mélançon, 2010; Hammouche *et al.*, 2010; Rogers *et al.*, 2010; Legault, 2009; Dion and Rhéaume, 2007; Rhéaume and Bandyayera, 2007; Legault and Rabeau, 2007, 2006; Goutier, 2006; Labbé *et al.*, 2006; Roy and Cadéron, 2006). For these reasons, it was considered appropriate to update the results of the volcanogenic massive sulphide (VMS) mineral potential assessment presented in Lamothe *et al.* (2005).

This short document summarizes the differences between the 2005 version and this updated 2011 version. The reader is referred to EP 2005-02 (Lamothe *et al.*, 2005) for the methodology and theoretical concepts behind the empirical (data-driven) mineral potential assessment of the VMS metallogenic model.

NEW IN 2011

The 2011 version of the Abitibi VMS model offers several developments that represent significant improvements over the 2005 product. These include both the way in which the data was processed and the nature of the parameters.

Technical improvements

All VMS data modelling for the 2011 version was done using the ModelBuilder tool in ArcGIS 9.3 (Appendix 1). The calculation of VMS potential in the Abitibi is now partially automated, allowing for several data processing hypotheses to be tested and their results compared. The possibility of quickly testing new parameters or different calibration sets represents a significant improvement to the mineral potential assessment process and will be applicable to all future metallogenic models developed by the MRNF.

It was possible to create this ModelBuilder model using ArcGIS 9.3 thanks to the inclusion of a collection of tools known as the *Spatial Data Modeller* (ArcSDM). The package was specifically developed for mineral potential assessments and includes the main tools needed for calibration (*Weights of Evidence*) and combination (*Fuzzy operators*)[2]. ArcSDM also includes several spatial analysis tools that were critical for some of the calculations in the VMS model.

Parameters in the 2011 version

Each parameter was selected as a function of: 1) its relevance to known features of the VMS metallogenic model; and 2) its ability to effectively predict the presence of mines as measured by the Weights of Evidence method (Lamothe *et al.*, 2005). Appendix 2 presents the inference model illustrating the retained parameters and how they were incorporated into the modelling process. The parameters were grouped into blocks representing six sub-models: 1) the sub-model for **Indicators of hiatus in volcanism**; 2) the sub-model for **Favourable lithologies**; 3) the sub-model for **Heat sources**; 4) the sub-model for **Hydrothermal activity;** 5) the sub-model for **EM anomalies**; and 6) the sub-model for the **Secondary environment**[3]. Grouping according to sub-model makes it easier to assess and understand the relative contribution of each family of parameters during the final integration. The use of six groups differs from the approach in 2005 when only three were defined. Moreover, 22 parameters were used in the current data analysis compared to 26 parameters in 2005. Appendix 3 presents the 22 parameters, their weighted distance classes, their measured contrast values[4] and their calculated fuzzy values[5] once all contrast values were obtained. The "Rank" column lists

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[1] Système d'Information Géominière du Québec.

[2] http://resources.arcgis.com/gallery/file/Geoprocessing-Model-and-Script-Tool-Gallery/details?entryID=B43F13B5-1422-2418-8867-84E8E8667754

[3] A seventh potential sub-model, **synvolcanic faults**, was omitted from the analysis given the great uncertainty concerning the age of faults in the Abitibi.

[4] Contrast is a measure of the predictivity of a parameter and the various classes it comprises; see Lamothe *et al*. (2005) for a detailed explanation.

[5] The fuzzy value calculation is based on an equation that assigns fuzzy values between 0 and 1 according to the minimum and maximum contrast values obtained from the weighting by the Weights of Evidence method; see Lamothe *et al* (2005) for additional explanations.

each parameter in order of importance (from 1 to 22) as a function of its maximum measured contrast value.

The following parameters in this updated version differ significantly from those used in 2005:

- the presence of andesite or basalt units with a favourable mafic fertility index (MFI) (Pearson, 2006); this replaces the earlier parameters of Group I, II and III volcanics as described in Barrie *et al*. (1993);
- the proximity of fertile rhyolite (Lesher *et al*., 1986); this replaces the high-temperature rhyolite parameter (Barrie, 1995);
- copper, lead or zinc anomaly targets in lake sediments, stream sediments or till; in 2005, these were defined on the basis of Abitibi drainage basins, but the 2011 version uses copper, zinc and silver targets in the secondary environment as defined by the natural break method (Lamothe, 2011);
- MEGATEM electromagnetic anomalies (GSC *et al.*, 2009) were adapted to the 6-channel system of SIGEOM and added to INPUT anomalies. Anomalies caused by anthropogenic sources were manually eliminated. To avoid the accidental inclusion of formational geophysical conductors, only relatively isolated anomalies (<2 anomalies/km^2) in a volcano-sedimentary context were used.

The 2011 version used the following data from SIGÉOM:

- about 176,422 rock analyses for the Abitibi, representing approximately 93,000 more analyses than in 2005;
- 95,094 drill holes, or about 2,795 more than in 2005;
- 53,449 *géofiche*s (outcrop descriptions) compared to 42,673 in 2005;
- 232,595 compilation outcrops compared to 174,617 in 2005;
- major updates of geological maps (interpretations, mapping) for map sheets 32D, 32E, 32F and 32G.

Assessing predictivity

There are 63 historical and current VMS-type base metal producers in the Abitibi. Of these, 12 randomly chosen mines (19%) were excluded from the training set used to measure parameter predictivity (see "Validation of the results"). These 12 mines were used instead for data processing validation by checking whether their locations were predicted by the high-favourability zones (HFZs) defined during the final step.

This assessment differs significantly from the 2005 assessment. The 2011 model calculates the predictivity of the parameters according to the production tonnage of each mine (Table 1). The production tonnage for each mine was divided into 5 weighted classes using the natural break method. These classes act as multipliers that can be applied to each of the mines. For example, the Waite mine, which belongs to class 3, is represented by three superimposed points (dots) in the calibration set. Because parameter weighting is done using the Weights of Evidence method, each additional superimposed point proportionally increases the predictivity of any parameters spatially associated with the bigger mines.

Combining parameters using fuzzy logic operators

The weighted images for the various parameters were combined using a fuzzy logic process, as was done for the 2005 model. At this point, the modelling is no longer entirely empirical (data-driven) and geological expertise influences how the model evolves.

The operators used for this study were FUZZYGAMMA and OR (Appendix 2). The OR operator outputs the maximum favourability values for juxtaposed cells on the combined maps. Nevertheless, if **the modeller is of the opinion** that the repeated proximity of several parameters is a strong indicator of the presence of VMS mineralization, it is possible to enhance the combination's resulting predictivity using the FUZZYGAMMA operator. The latter allows the normally obtained combination

TABLE 1 – List of volcanogenic massive sulphide producers used for parameter weighting. The column on the right indicates the multiplier applied to the point representing the mine. The Astoria mine is thus represented by a single dot, whereas the Selbaie mine is represented by 5 superimposed dots.

Name of the deposit	Production (millions of tonnes)	Rank (multiplier)
Mine Wright (Villa, Decouverte Coignac)	< 2.72	1
Mine Dunraine (Mine Rainville)		
Mine Louvem		
Mine Mid-Canada (Zone Sud)		
Mine Aldermac, Lentille no 4 (exploitée)		
Mine Astoria		
Mine Aldermac,Lentille no 3 (exploitée)		
New Insco (Fabie Bay)		
Ansil (Lentille Principale)		
Mine Waite-Amulet-F		
Mine East Waite		
Newbec		
Mine Halliwell		
Corbet		
Mine Joliet Québec		
Mine Delbridge No 2		
Mine Eldona No 1		
Mine Lyndhurst		
Mine Estrades (Golden Hope)		
Phelps-Dodge		
Mine Bell-Allard Sud		
Mine Bell Allard		
Mine New Hosco		
Mine Garon Lake		
Mine Radiore 2 (Ou B)		
Mine Cooke		
Mine Barvue (Abcourt)	2.72 - 7.08	2
Norbec		
Waite-Amulet (C, A et Bluff)		
Millenbach (Lentille Principale)		
Millenbach (Zone no. 14)		
Mine Gallen (West McDonald)		
Mine Orchan		
Mine Isle-Dieu Mattagami		
Mine Norita		
Mine Norita-Est		
Mine Manitou-Barvue	7.08 -12.25	3
Mine Waite		
Mine Bouchard-Hébert (Mobrun), Lentille Principale		
Mine Bouchard-Hébert (Mobrun), Lentille 1100		
Mine Bousquet No 2		
Mine Normétal (Normetmar)		
Mine Poirier		
Mine Gonzague Langlois		
Louvicourt	12.25 - 25.65	4
Quémont		
Mine Bousquet No 1		
Horne Upper H	> 25.65	5
Horne Zone #5		
Mine Donald J. Laronde (Dumagami)		
Mine Selbaie (Zone A1)		

results to be adjusted by a factor “F” using the “AND” and “OR” operators, and generates values that increase proportionally to the “F” value. When combining two or more maps, the use of the FUZZYGAMMA operator in conjunction with a high “F” factor (F ≥ 0.9) generates a **result above the maximum value of the superimposed cells on the combined maps**.

The applied factor is indicated in parentheses next to each FUZZYGAMMA operator in Appendix 2. The degree of enhancement is proportional to the predictivity of the combined parameters, varying from 0.8 (fairly low) for parameters with moderate predictivity, to 0.98 (significant) for strongly predictive parameters. The final result derived from the various combinations is illustrated in Appendix 2 and constitutes the final favourability map for VMS potential in the Abitibi (Appendix 4 or the digital map accompanying the report).

DETERMINING HIGH-FAVOURABILITY ZONES AND TARGETS

Once the favourability map was finalized, it was possible to: 1) define high-favourability zones (HFZs) associated with VMS-type mineralization to help focus mineral exploration in the Abitibi; and 2) establish a number of targets constituting the unstaked portions of the HFZs at the time of writing this report.

In order to define a high-favourability zone, it was first necessary to establish a minimum favourability threshold value above which a zone’s favourability acquires significant predictivity for the presence of VMS-type mineralization. To define this threshold, favourability values for 63 VMS mines in the Abitibi were plotted on a quantile-quantile diagram (Figure 1).

The slope of the mines plotted in Figure 1 shows breaks which, based on an analysis of the weighted values, can be attributed to some of the sub-models involved in the data processing. In fact, three plateaus are associated with the fields for the following sub-models: “heat source”, “hydrothermal alteration” and “EM anomalies”. Although these three parameter sub-models account for most of the cases of cell favourability enhancement, each break marks the point at which maximum values come into play for each sub-model. Theoretically, it would be possible to eliminate these abrupt variations in favourability by adjusting factors in the FUZZYGAMMA operator used for the sub-models in question.

A main population can be distinguished among the plotted points, defined by values above the minimum threshold of 0.759. This main population comprises 59 (94%) of the 63 producing VMS mines documented in the region (Figure 1). The second population consists of 4 mines below the minimum threshold (the Wright mine falls outside the range of the diagram), which were underestimated by the process. This minimum threshold was used to identify and group cells with values equal to or above 0.759, and convert them into polygons on the final favourability map. These polygons constitute high-favourability zones (HFZs) for which the geological setting represents a metallogenic potential statistically equivalent to the metallogenic potential associated with the geological settings of the 59 mines in the study. These polygons are included among the digital products associated with this document.

The final version of the targets was based on the distribution of active and pending mining titles as at April 9, 2011. On that date, unstaked portions of the HFZs formed 365 targets with strong potential for VMS-style mineralization. The locations of these targets, the graphical representation of favourability, and the distribution of the HFZs can be consulted in Google Earth format by clicking the “Mineral Potential” link on the MRNF publications page (http://www.mrnf.gouv.qc.ca/english/mines/publications/publications-maps.jsp) or by consulting the digital products associated with this document.

VALIDATION OF THE RESULTS

The blue dots on Figure 1 represent 12 VMS mines (Table 2) that were not used for weighting the parameters. All these mines fall above the minimum threshold used to define HFZs and were thus correctly predicted by the model.

TABLE 2 – List of VMS producers excluded from the weighted mine set for us as model validators. The right-hand column displays the favourability value as determined by the final VMS mineral potential assessment. All values are above the minimum threshold (0.759) used to define high-favourability zones (HFZ).

Name of the deposit	Favourability
Mine Robb-Montbray (Inmont)	0.923
Mine Aldermac, Lentille no 5 (exploitée)	0.923
Mine Lac Mattagami	0.919
Mine East Sullivan (Sullico)	0.862
Lemoine	0.824
Mine Vauze	0.823
Mine Joutel Copper	0.821
Mine Agnico-Eagle (Ouest et Telbel)	0.819
Mine Coniagas	0.805
Mine Donald J. Laronde (Dumagami), Zone 4	0.796
Mine Donald J. Laronde (Dumagami), Zone Sud	0.796
Horne Lower H	0.764

Figure 2 presents two diagrams illustrating the effectiveness of the final favourability map using 63 VMS mines in the Abitibi. On the y-axis, the plots show the cumulative percentage of mines as a function of their favourability, and on the x-axis, the cumulative percentage of the surface occupied by the cells of the potential map in order of decreasing favourability. Figure 2b represents the enlarged left side of Figure 2a. The figure shows that 97% of the mines are predicted using only 5% of the upper favourability surface of the map.

ACKNOWLEDGEMENTS

The contribution of Jean Goutier was very much appreciated, particularly for defining the synvolcanic plutonic intrusions. I would also like to thank Charles Maurice for his invaluable suggestions concerning some of the processing steps.

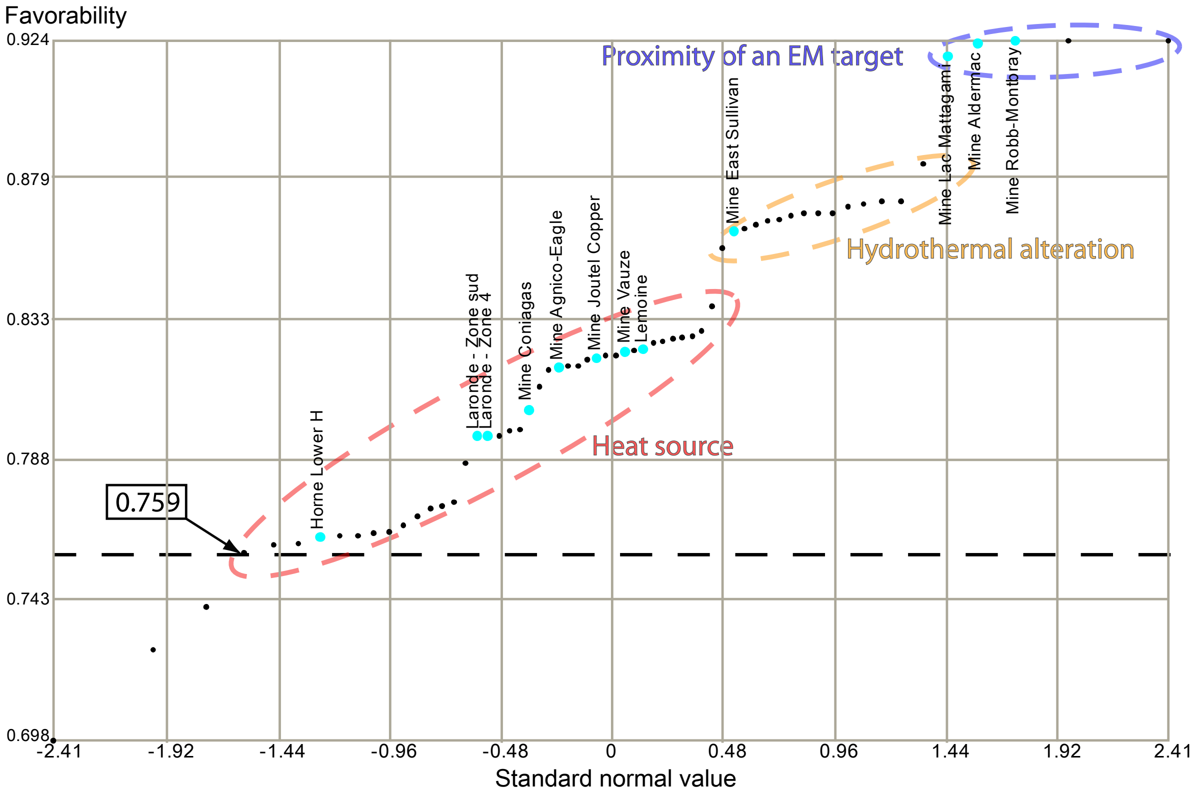

FIGURE 1 – Determination of the minimum threshold for high favourability using a quantile-quantile diagram. Values on the y-axis correspond to the measured favourability value on the final favourability map for each of the 63 VMS mines in the Abitibi. Cells on the final map with values above 0.759 cover 94% of the mines. The blue dots correspond to the 12 VMS mines that were used to validate the model and thus were not used for weighting the parameters. The visible breaks in the distribution are due to the particularly strong influence of parameters associated with the indicated sub-models.

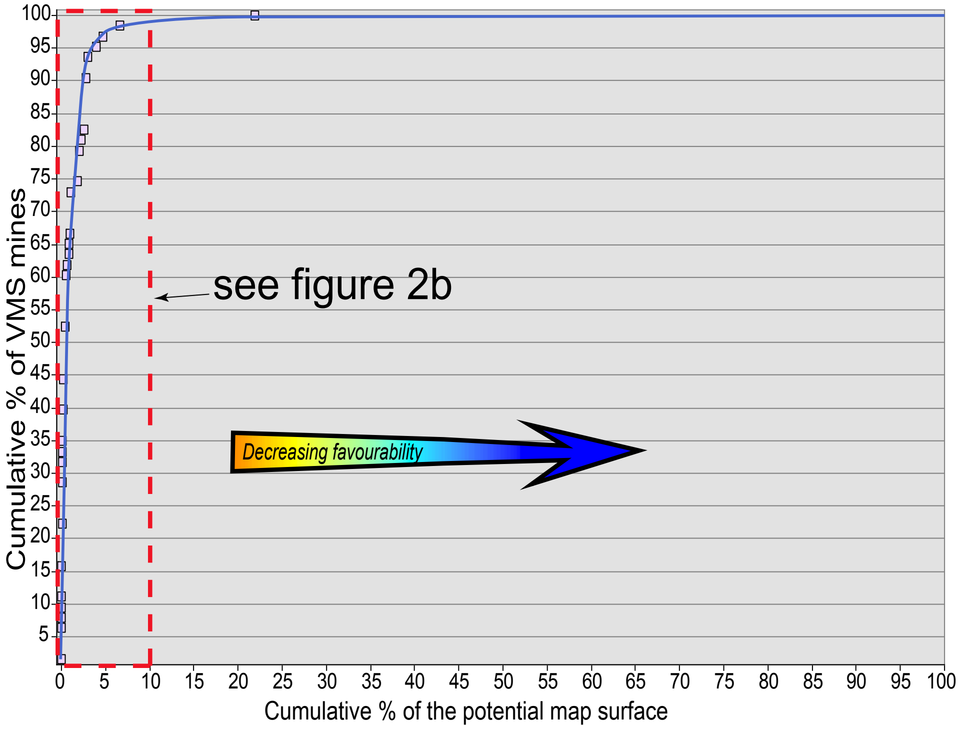

FIGURE 2A – Predictivity of the favourability map obtained by "hybrid fuzzy logic". The diagram shows: 1) on the x-axis, the cumulative surface (in percentage) of the mineral potential map cells in order of decreasing favourability; and 2) on the y-axis, the cumulative percentage of mines covered by the cells.

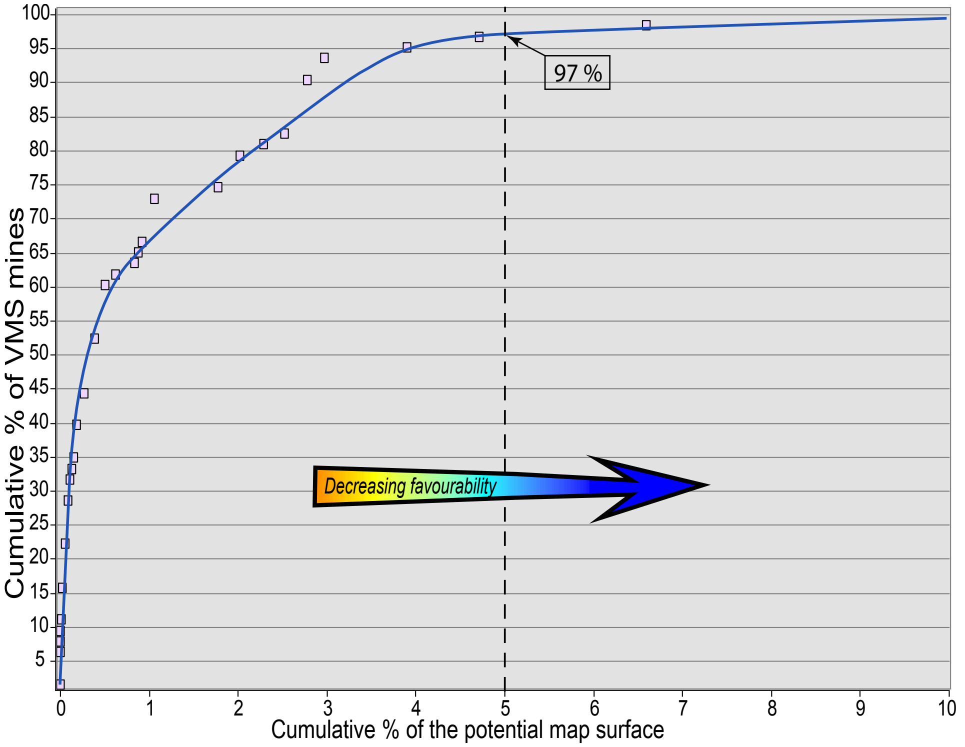

FIGURE 2B – Enlarged portion of Figure 2a. About 97 % of the 63 VMS-type mines are covered by the group of the most favourable cells, which accounts for 5% of the map surface.

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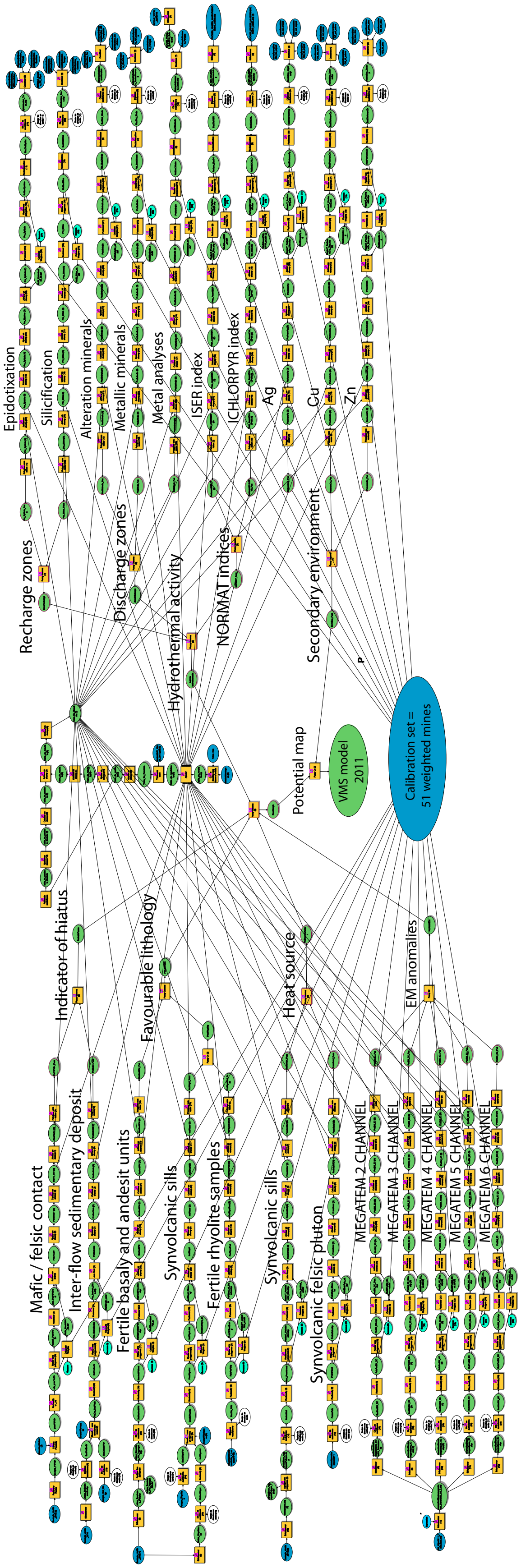
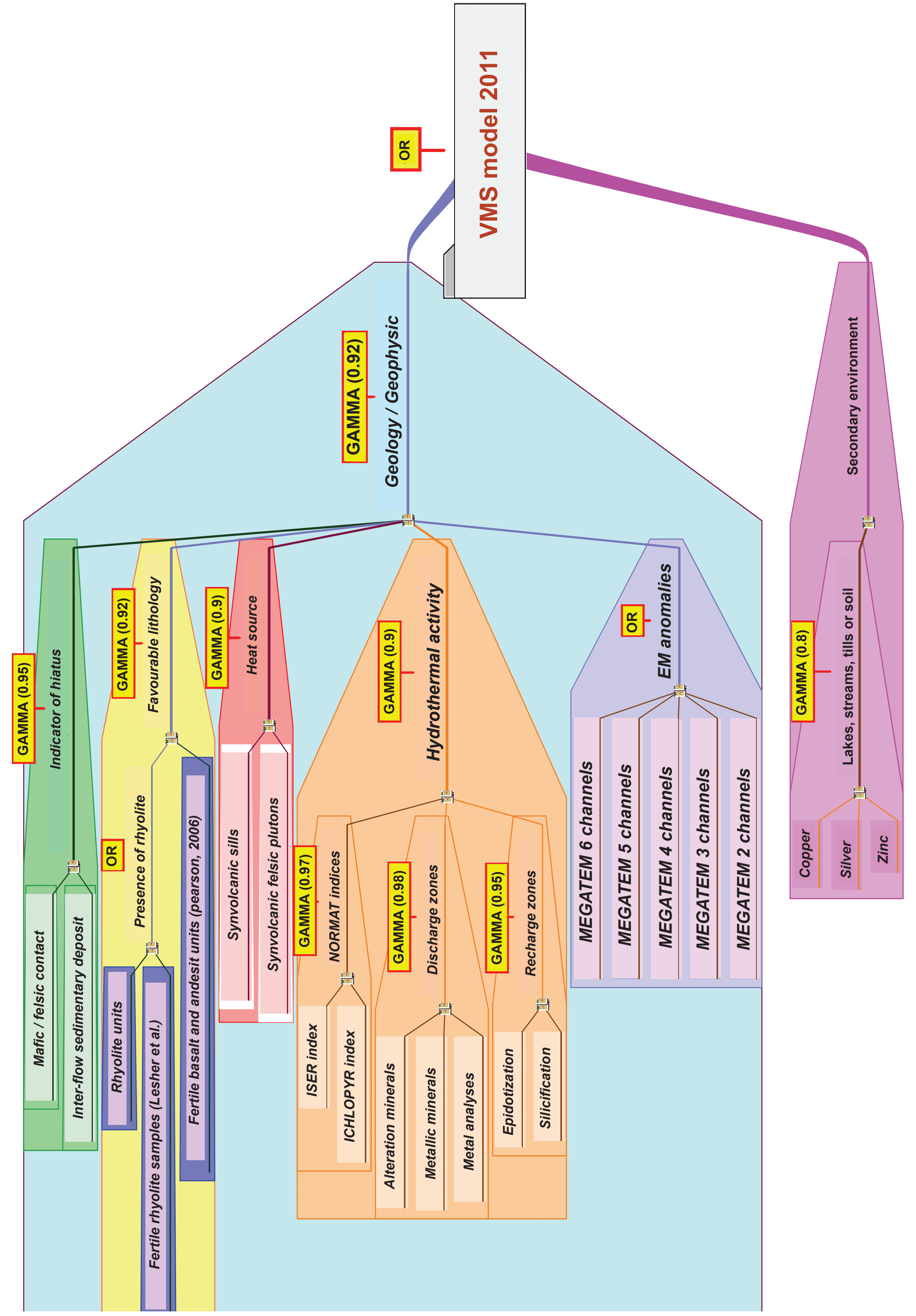
APPENDIX 1

Schematic overview of the process for modelling VMS potential in the Abitibi using ModelBuilder



APPENDIX 2

Inference model for VMS potential in the Abitibi illustrating the weighted parameters. The parameters were integrated using the fuzzy logic operators “FUZZYGAMMA” and “OR” operators (yellow boxes) to produce the final map.



APPENDIX 3

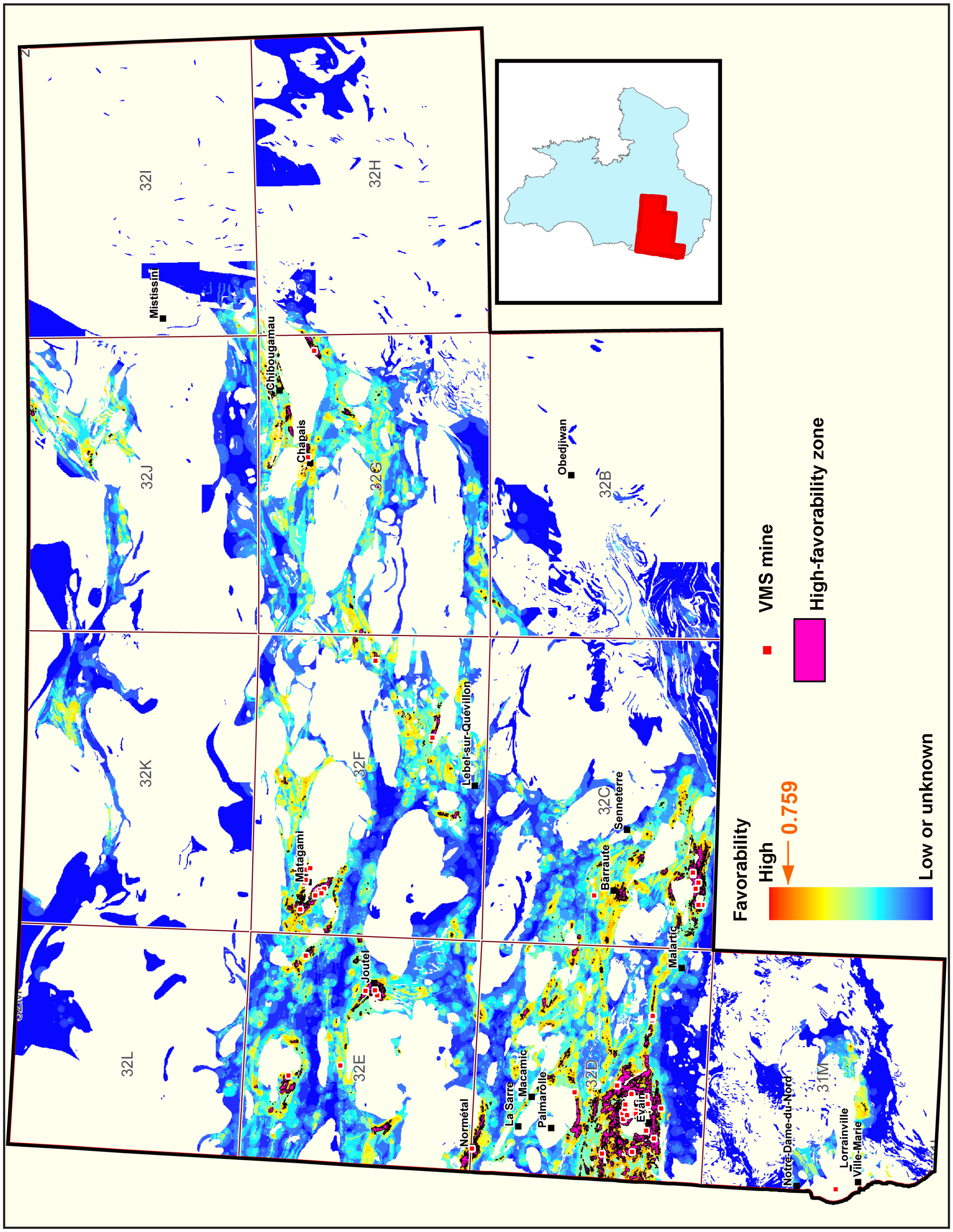
Contrast values for the 22 parameters of the VMS model converted into fuzzy values. Ranking indicates the order of importance for the parameter as established by its maximum measured contrast value.

Distance (m)	Contrast	Fuzzy value	Rank
Indicators of hiatus in volcanism			
Proximity of a contact between a felsic lava unit and a intermediate to ultramafic lava unit			
< 100	5.334	0.740	9
100-200	4.042	0.682	
200-300	3.734	0.668	
300-400	3.277	0.647	
400-500	2.635	0.618	
500-600	2.126	0.596	
600-700	1.813	0.581	
700-800	1.784	0.580	
800-900	1.941	0.587	
900-1400	1.808	0.581	
> 1400	-7.463	0.001	
Proximity of an inter-flow sedimentary horizon			
0	4.035	0.681	14
0-100	3.498	0.657	
100-200	2.199	0.599	
> 200	-7.463	0.001	
Proximity of a favourable lithology			
Presence of rhyolite			
0	4.248	0.691	12
1-400	4.239	0.690	
400-800	1.321	0.559	
> 800	-6.259	0.219	
Proximity of a fertile rhyolite			
> 600	-7.463	0.165	8
< 200	5.410	0.743	
200-400	4.920	0.721	
400-600	3.666	0.665	
Presence of andesite or basalt units with favourable MFI			
Favorabilité Dans BasAndesIFM	2.809	0.626	21
Favorabilité Hors BasAndesIFM	-2.809	0.374	
Proximity of a heat source			
Proximity of interm. or maf. synvolcanic sills			
< 100	4.002	0.680	15
100-200	2.423	0.609	
200-300	1.988	0.589	
300-400	1.803	0.581	
400-500	1.738	0.578	
500-600	1.757	0.579	
600-700	1.807	0.581	
700-800	1.709	0.577	
800-900	1.446	0.565	
900-1000	1.026	0.546	
1000-3100	1.040	0.547	
> 3100	-7.438	0.002	
Proximity of synvolcanic felsic plutons			
< 1 000	3.797	0.671	17
1 000-2 000	2.263	0.602	
2 000-3 000	1.922	0.586	
3 000-4 000	2.027	0.591	
4 000-5 000	0.805	0.536	
> 5 000	-7.433	0.002	
Evidence of hydrothermal activity			
Proximity of an anomalous NORMAT alteration index			
Proximity of an anomalous ISER index			
< 100	7.155	0.822	4
100-200	6.812	0.806	
200-300	5.390	0.742	
> 300	-7.452	0.001	
Proximity of an anomalous ICHLOPYR index			
< 100	6.356	0.786	6
100-200	6.454	0.790	
200-300	4.895	0.720	
300-400	4.528	0.703	
> 400	-7.452	0.001	
Discharge zone			
Proximity of alteration minerals			
< 100	6.659	0.799	5
100-200	2.663	0.620	
200-300	1.303	0.559	
300-400	1.108	0.550	
400-500	0.829	0.537	
500-600	0.403	0.518	
600-700	0.286	0.513	
700-800	-0.230	0.490	
800-900	-0.152	0.493	
900-2 100	-0.955	0.457	
> 2 100	-7.463	0.001	
Proximity of mineralization			
< 100	11.127	0.999	1
100-200	1.913	0.586	
200-300	0.824	0.537	
300-400	0.464	0.521	
400-500	0.053	0.502	
500-1 800	-0.314	0.486	
> 1 800	-7.463	0.001	
Proximity to an anomalous metal content			
< 100	8.173	0.867	2
100-200	4.242	0.691	
200-300	3.707	0.667	
300-400	3.459	0.655	
400-500	3.033	0.636	
500-600	3.297	0.648	
600-700	2.458	0.610	
700-800	2.730	0.623	
> 800	-7.463	0.165	

Distance (m)	Contrast	Fuzzy value	Rank
Evidence of hydrothermal activity (continued)			
Recharge zone			
Proximity of epidotization			
< 100	4.561	0.705	11
100-200	3.271	0.647	
200-300	3.193	0.643	
300-400	3.172	0.643	
400-500	3.068	0.638	
500-600	2.855	0.628	
600-700	2.417	0.609	
700-800	2.388	0.607	
800-900	2.280	0.602	
900-1 000	1.870	0.584	
1 000-1 100	1.794	0.581	
1 100-1 200	1.861	0.584	
1200-1 300	1.931	0.587	
1 300-1 400	1.865	0.584	
1 400-1 500	1.732	0.578	
1 500-2 500	1.509	0.568	
> 2 500	-7.463	0.001	
Proximity of silicification			
< 100	7.215	0.824	3
100-200	3.845	0.673	
200-300	3.376	0.652	
300-400	3.159	0.642	
400-500	3.165	0.642	
500-600	2.749	0.624	
600-700	2.770	0.624	
700-800	2.652	0.619	
800-900	2.490	0.612	
900-1 000	2.585	0.616	
1 000-1 100	2.611	0.617	
1 100-1 200	2.363	0.606	
1 200-1 300	1.625	0.573	
1 300-1 400	1.514	0.568	
1 400-1 500	1.201	0.554	
1 500-1 900	1.267	0.557	
> 1 900	-7.463	0.001	
Presence of an EM anomaly			
Proximity of a MEGATEM anomaly			
Proximity of a 6-channel MEGATEM anomaly			
< 200	4.859	0.718	10
200-400	3.326	0.649	
> 400	-3.989	0.233	
Proximity of a 5-channel MEGATEM anomaly			
< 400	3.186	0.643	20
> 400	-3.186	0.287	
Proximity of a 4-channel MEGATEM anomaly			
< 100	6.061	0.772	7
100-300	3.854	0.673	
> 300	-4.463	0.201	
Proximity of a 3-channel MEGATEM anomaly			
< 200	3.929	0.677	16
200-300	3.678	0.665	
> 300	-3.815	0.201	
Proximity of a 2-channel MEGATEM anomaly			
< 200	2.711	0.622	22
> 200	-2.711	0.318	
Secondary environment			
Proximity of lake, stream, till or soil target (EP 2010-01)			
Proximity of a copper target			
0	4.230	0.690	13
1-200	3.878	0.674	
200-400	3.876	0.674	
400-600	3.943	0.677	
600-800	4.025	0.681	
800-1 000	4.129	0.686	
1000-1 200	4.144	0.686	
1 200-1 400	3.105	0.640	
1 400-2 200	1.848	0.583	
> 2 200	-7.452	0.001	
Proximity of a silver target			
0	3.532	0.659	19
1-1 000	3.344	0.650	
1 000-2 000	3.404	0.653	
2 000-3 000	3.345	0.650	
3 000-4 000	2.053	0.592	
4 000-5 000	2.109	0.595	
5 000-6 000	2.151	0.597	
6 000-7 000	2.182	0.598	
> 7 000	-7.452	0.001	
Proximity of a zinc target			
0	3.796	0.671	18
< 500	3.389	0.652	
500-1 000	3.214	0.644	
1 000-1 500	2.662	0.620	
1 500-2 000	2.637	0.619	
2 000-2 500	2.102	0.594	
2 500-4 000	0.892	0.540	
> 4 000	-7.452	0.001	

APPENDIX 4

Final favourability map for VMS potential in the Abitibi.



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