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SHADED-RELIEF MAPS OF GEOCHEMICAL DATA TO DELINEATE GEOLOGICAL STRUCTURES

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ABSTRACT

The presentation of geochemical data as shaded-relief images can greatly increase the amount of useful information conveyed, just as can be accomplished with shaded-relief images of topographic and geophysical data. The creation of enhanced images of geochemical data requires the conversion of the point data to a raster format and some preliminary filtering to improve the geochemical signal to noise ratio and the visual appearance of the final image. To perform these initial steps successfully, a thorough understanding of the data's characterisics, both spatial and statistical, is necessary. The effects of applying different filters to the regional lake-sediment data for Newfoundland on the appearance of shaded-relief images is illustrated.

INTRODUCTION

Image-processing of geochemical data provides a powerful technique for clarifying subtle but significant spatial patterns and, in some cases, cryptic features are revealed that were completely hidden in a background of noise. The use of image-processing is familiar to many geologists as applied to satellite imagery and geophysical data. A technique that is widely applied to magnetic survey data is the creation of shaded-relief images to highlight geological structures. Application of the same technique to lake-sediment geochemical data is proving similarly effective in delineating regional structures.

Geochemical surveys that are designed to map element-distribution patterns define chemical surfaces that resemble topographic surfaces or geophysical potential fields (e.g., from aeromagnetic surveys). Structural features that are reflected in these geochemical (or geophysical) surfaces arise from three main geological situations: 1) the juxtaposition of two geological units of contrasting composition (e.g., along an intrusive or faulted contact); 2) alteration along a linear zone (commonly fault-controlled); and 3) the offset of continuous geological units along a fault. The first two give rise to an abrupt change in geochemical level, which in the first situation usually provides merely further confirmation of a known feature, but may also provide new information in the case of mapping hydrothermal alteration zones. Similarly, in the third situation, the geochemical delineation of an obvious, geologically defined fault provides little new insight, but more subtle discontinuities related to basement structure may also be revealed.

Geochemical surfaces are displayed commonly as contour maps (Plate 1) that portray general variations in chemical concentration. Monochrome shaded-relief images (Plate 2) emphasize local, relative variations in geochemical level, whereas colour shaded-relief images (Plate 3) depict both local and overall variations in level and thus present more of the intrinsic information in the geochemical dataset. Both types of shaded-relief image have their uses and other types of image-processing are available for other applications (e.g., anomaly recognition). Most image-processing is based on gridded or raster data, and the initial gridding must be done paying due attention to the data's characteristics. This will ensure that all the relevant information is retained, without the introduction of artifacts during data processing.

DATA PREPARATION

When interpolating geochemical data from an irregularly distributed set of sample sites to a regular grid, it is possible to effect varying degrees of smoothing. For example, if regional trends are the main interest, then data from several nearby sites may be averaged to minimize the effects of local variation and outliers (including anomalies), resulting in a smooth map of broad-scale trends. If anomalous values are the main concern, then as much as possible of the local variation must be retained. The creation of shaded-relief images is but one of several methods of image enhancement possible with geochemical data; filtering techniques for anomaly recognition form another important class. To create a gridded dataset useful for most image-processing techniques, it is efficient to adopt a simple and conservative method of gridding that minimizes smoothing and retains as much detail (including noise) as possible. To this general-purpose gridded dataset, various filters may be applied to produce secondary grid-files for specific applications (anomaly recognition, delineation of regional trends, etc.). The choice of an appropriate approach for the creation of the initial gridded dataset is critical to the success of subsequent data analysis, and depends upon an appreciation of the data's characteristics, both geochemical and spatial. This appreciation is gained through the following steps.

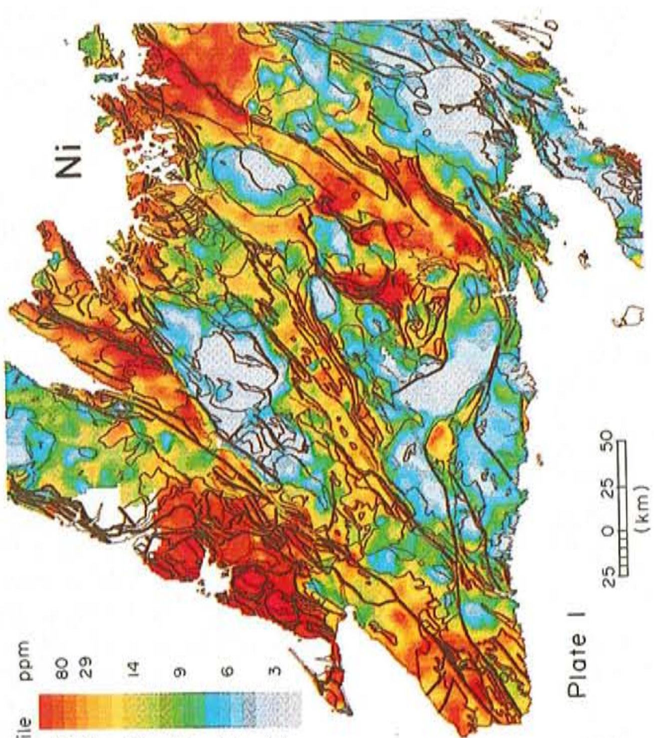

Plate 1

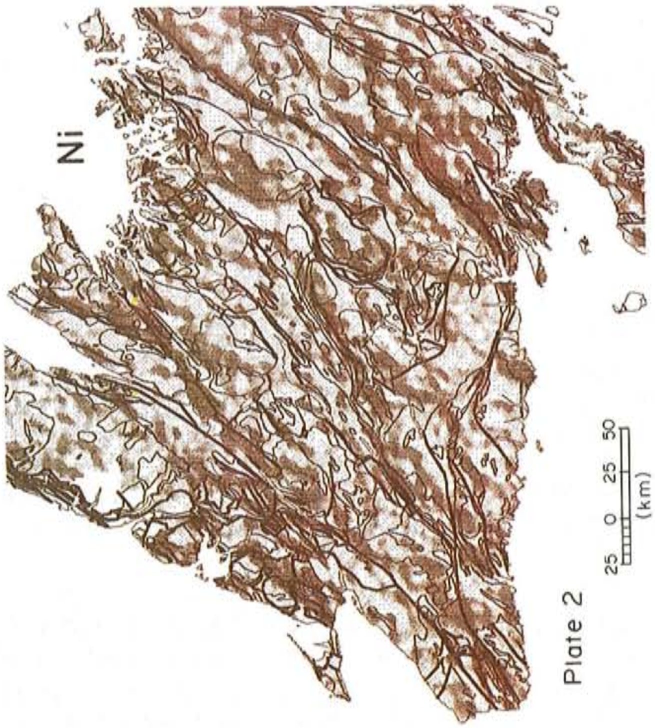

Plate 2

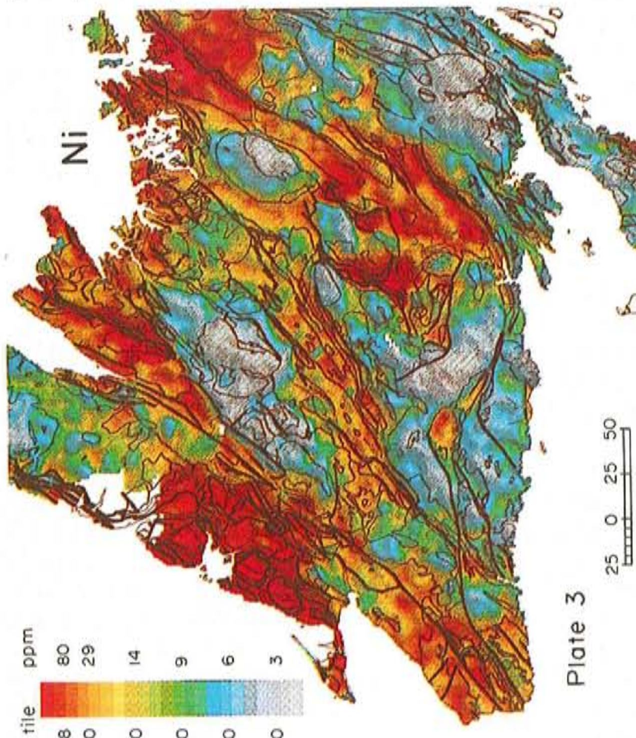

Plate 3

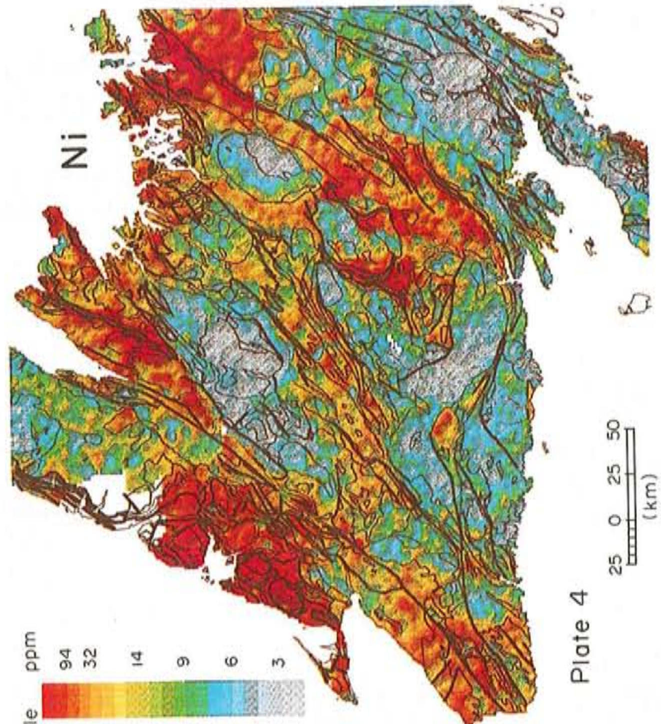

Plate 4

DATA EVALUATION

Examination of Element Frequency Distributions

This is accomplished through the calculation of basic statistics (mean, median, standard deviation, coefficient of variation and range) and probability plots, using a statistical package such as UNISTAT (Nolan, 1990). For elements that are clearly not normally distributed a transformation is recommended. Usually a log transformation is used for trace elements having a high coefficient of variation ($\geqslant 0.5$). Outliers and major populations are also identified at this stage. Outliers can be removed, although with the use of robust filters (Chork and Mazzucchelli, 1989) in subsequent processing this may not be required, and in the creation of the initial grid they are usually retained. The identification of any major, distinct populations may aid later interpretation of the enhanced images. Contour levels are chosen from the probability plot, using either the approach of Sinclair (1976) or on a percentile-based scheme.

Evaluation of Data Quality and Sources of Error

Where available, data from site duplicates should be used to obtain an indication of data reproducibility for each element with respect to the overall range of the data through a simple analysis-of-variance approach (Garrett, 1973). If the results are available from more complex, nested-sampling designs (e.g., Garrett and Goss, 1980) that permit variance to be measured at more levels (laboratory, site, sample cell, etc.), this information should be evaluated too, but the most important level is at the sample site.

Examination of the Spatial Distribution of the Data

A custom-written program (GRIDVIEW) is used to determine an appropriate size for the the grid cell in the initial interpolation of the data from the irregularly distributed sample sites to a regular grid. An efficient cell size is one where the proportion of cells containing a single site is a maximum, while the proportions of cells containing either no sites or multiple sites are minima; Chork and Mazzucchelli (1989) note that this type of approach typically results in an average of about 1.5 sites per cell (excluding empty cells). GRIDVIEW allows the cell size to be altered interactively, and calculates a histogram of the number of sites per cell for each cell size chosen. The program also displays the grid and the sample sites on the screen so that the uniformity of the sample coverage can be assessed visually. The data used here in the illustrations have a uniform random distribution, allowing the use of standard random gridding techniques to prepare a gridded dataset. If the sample-site distribution is quite uneven, alternative gridding methods may be required, such as the gap-filling approach of Chork and Cruikshank (1984).

IMAGE CREATION

Initial Gridding

This is carried out on the data, log-transformed as appropriate (see Examination of Element Frequency Distributions section), using a grid-cell size indicated from an examination of the spatial distribution of the data. At this stage as much of the original character of the data as possible is conserved (including noise) by interpolating the value at each grid node from up to four nearest points lying within 2.5 times the length of the grid-cell side, and giving more weight to values from nearer points than more distant points (typically, an inverse of the distance squared is used as the weighting factor).

Initial Image Assessment

Shaded-relief images are created using a custom-written program DISPLAY (Kilfoil, 1990, *this volume*), which permits gridded data to be rapidly displayed on a microcomputer with a VGA monitor. DISPLAY, which adds colour capability to a grey-scale program by Teskey and Broome (1984), offers several options interactively, including: choice of colour or grey shades, inclination and declination of illumination, windowing (through decimation), and the display of two images side by side, with independent display parameters. The image is evaluated subjectively for the clarity with which it shows geochemical features. The image at this stage usually contains a good deal of local variation, which gives it a 'pockmarked' appearance that obscures the more continuous geochemical features (Plate 4). The degree of this

Plate 1. *Colour contour map of Ni in lake sediment in Newfoundland plotted on a geological framework digitized from Colman-Sadd* et al., *1990.*

Plate 2. *Greytone shaded-relief image of Ni in lake sediment in Newfoundland after filtering using a 3 by 3 cell ATM filter, and two passes of a 3 by 3 cell moving-average-filter, plotted on a geological framework digitized from Colman-Sadd* et al., *1990. Illumination from 315°*

Plate 3. *Colour shaded-relief image of Ni in lake sediment in Newfoundland after filtering using a 3 by 3 cell ATM filter, and two passes of a 3 by 3 cell moving-average-filter (plotted on a geological framework digitized from Colman-Sadd* et al., *1990). Illumination from 315°*

Plate 4. *Colour shaded-relief image of Ni in lake sediment in Newfoundland after initial gridding (no filtering), plotted on a geological framework digitized from Colman-Sadd* et al., *1990. Illumination from 45°*

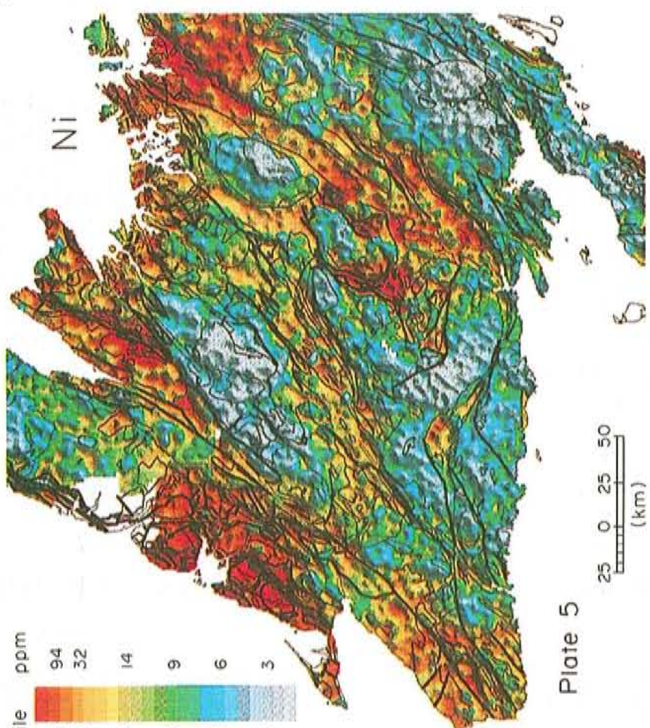

Plate 5

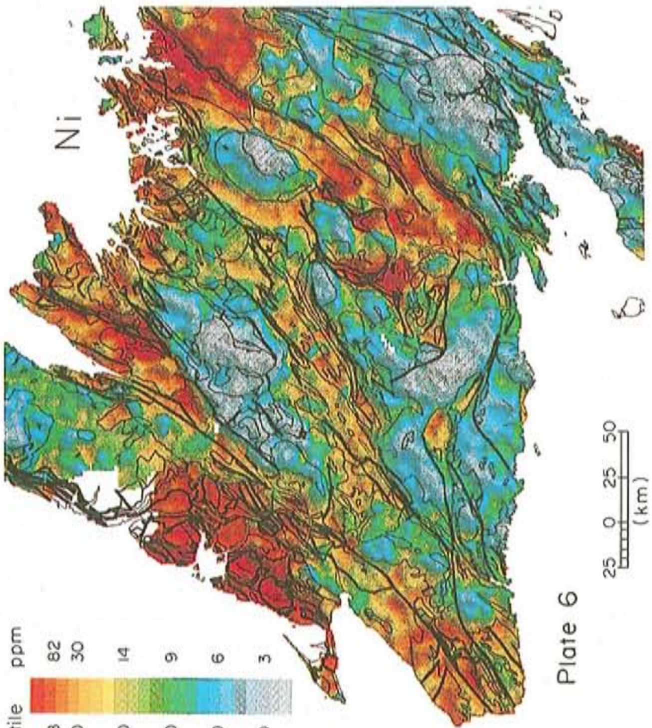

Plate 6

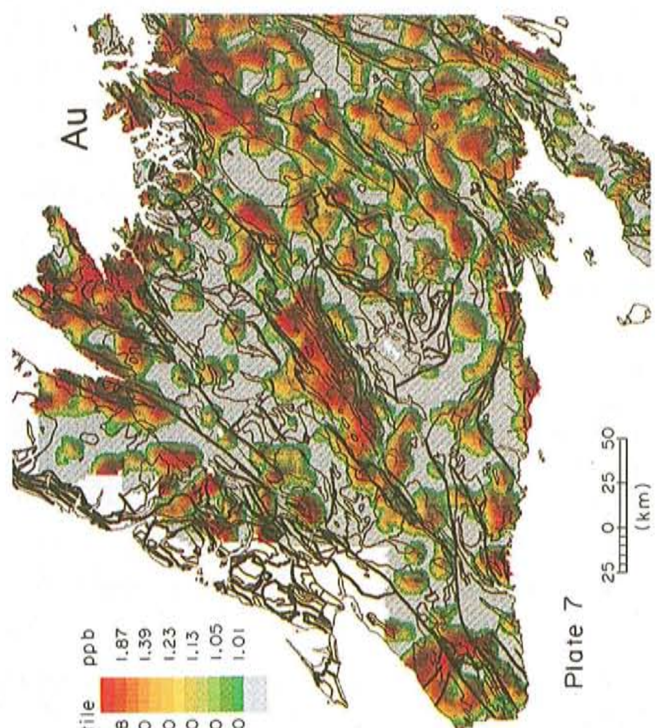

Plate 7

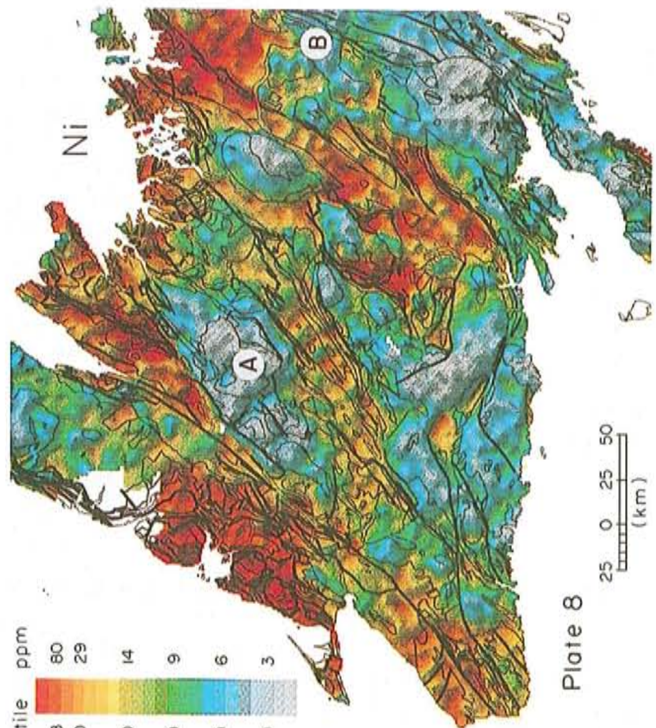

Plate 8

local variation (or noise) varies from element to element and is usually least noticable for elements whose variance at the sample site level is small compared with their overall variance (see Evaluation of Data Quality and Sources of Error section). It also varies with shading direction, and is least noticeable when illumination is perpendicular to the main structural grain (Plate 5).

Smoothing and Filtering

Much of the noise in the images at this stage is a result of the parameters deliberately chosen in the initial gridding (see Initial Gridding section). Several filtering methods to smooth geochemical data have been described. The simplest in concept is a moving average type (Howarth, 1983, chap. 5), using a n x n pixel window that is passed over the data one or more times. The degree of smoothing increases as n increases, and with the number of passes of the filter over the data. Inherent in the moving average filter are assumptions about the frequency distribution of the geochemical data (e.g., that the data are from a normal distribution). These assumptions are seldom tested in practice, and commonly are not satisfied, although in many cases this is more of a concern to statisticians than geologists as the resulting images are geologically useful. However, robust alternatives are available that require fewer and less stringent assumptions to be met, and therefore, provide images that are more acceptable both practically and theoretically. The Median filter and the Adaptive Trimmed Mean (ATM) filter (Chork and Mazzucchelli, 1989) are two such approaches. The Median filter provides a conservative estimate of regional trends, but inherently removes almost all anomalies. The ATM filter affords a robust and effective approach to smoothing regional geochemical data while retaining a good deal of local data variance (including anomalies). To produce a satisfactory image, the window size of the filter is varied and the results displayed and evaluated subjectively. The larger the filter, the greater the area over which the data are generalized and the more the fine detail is lost, so its size depends in part on the degree of generalization required. The results of using a 3 by 3 cell ATM filter (representing a 6 by 6 km window) on Ni are shown in Plate 6. This image is still somewhat grainy and this graininess can be diminished by further smoothing using a simple moving average filter on the log-transformed data (Plate 3). This approach works well even for an element such as Au, where over 80 percent of the values are below the analytical detection limit, and the higher values are noisy (Plate 7). The adaptive trimmed mean program was modified from Rock (1987).

During smoothing, the variance of the data is reduced. Typically, however, there is a proportionally greater reduction in the noise component than the significant geochemical patterns, resulting in a better signal to noise ratio. The random noise tends to cancel, whereas the non-random geochemical signals tend to reinforce. To display subtle features after filtering it, is advantageous to stretch the range of residual values to utilize the full colour range available on the image display system, a feature offered by DISPLAY, and most commercial programs. Final images are best displayed on a monitor having a resolution higher than a VGA screen. The shaded-relief images can be printed by capturing the DISPLAY image using commercial software designed for this purpose. The figures presented here were printed through GEOSOFT, a commercially available, general purpose, mapping system. This permits the data to be plotted at any desired scale with a geochemical legend. The data can be plotted on either a topographic or geological base or both, with shading patterns from one or more directions of illumination.

DISCUSSION

The choice of parameters used to produce shaded-relief images of a geochemical dataset is dictated ultimately by the resolution of the survey itself. The term resolution as applied to a geochemical survey has not been defined clearly, but implicitly it refers to the subtlest geochemical feature that can be detected with some specified degree of confidence. The subtlety could be due to either the size of the feature (in which case sample spacing and the representivity of the sample medium would be the limiting factors on resolution) or its geochemical contrast (where data quality would be the more important factor). Sample spacing is fixed during survey design and is common for all elements, but representivity and quality will vary from element to element (representivity

Plate 5. *Colour shaded-relief image of Ni in lake sediment in Newfoundland after initial gridding (no filtering), plotted on a geological framework digitized from Colman-Sadd* et al., *1990. Illumination from 315°*

Plate 6. *Colour shaded-relief image of Ni in lake sediment in Newfoundland after filtering using a 3 by 3 cell ATM filter (plotted on a geological framework digitized from Colman-Sadd* et al., *1990). Illumination from 315°*

Plate 7. *Colour shaded-relief image of Au in lake sediment in Newfoundland after filtering using a 3 by 3 cell ATM filter, and one pass of a 3 by 3 cell moving-average-filter (plotted on a geological framework digitized from Colman-Sadd* et al., *1990). Illumination from 315°*

Plate 8. *Colour shaded-relief image of Ni in lake sediment in Newfoundland after filtering using a 3 by 3 cell ATM filter, and two passes of a 3 by 3 cell moving-average-filter (plotted on a geological framework digitized from Colman-Sadd* et al., *1990). Illumination from 225. Note linear 'A' (the 'Buchans linear') and linear 'B', both of which crosscut the main northeast-southwest structural grain.*

varying with the mobility of the various elements). Data quality can be measured from site-duplicate samples, and representivity can be estimated in relative terms from a nested sampling design or variograms, but the resolution cannot be exactly quantified because of the size-contrast ambiguity. The resolution of geochemical surveys for a geochemical feature of specified size and contrast is a function of both sample spacing and representivity (Figure 1). Thus, for a given survey, resolution varies from element to element, being a function of the different element representivities, or, to look at it from a different perspective, the resolution of a low-density survey for Ni (one site per 200 to 400 km²) is roughly equivalent to the resolution for Au in a much higher density survey (one site per 7 km²) using the same sample medium (lake sediment). Other elements are intermediate between Ni and Au (e.g., Sb), and a rough guide to the relative order of resolution in a survey is given by the ratios of total-data variance to within-site variance.

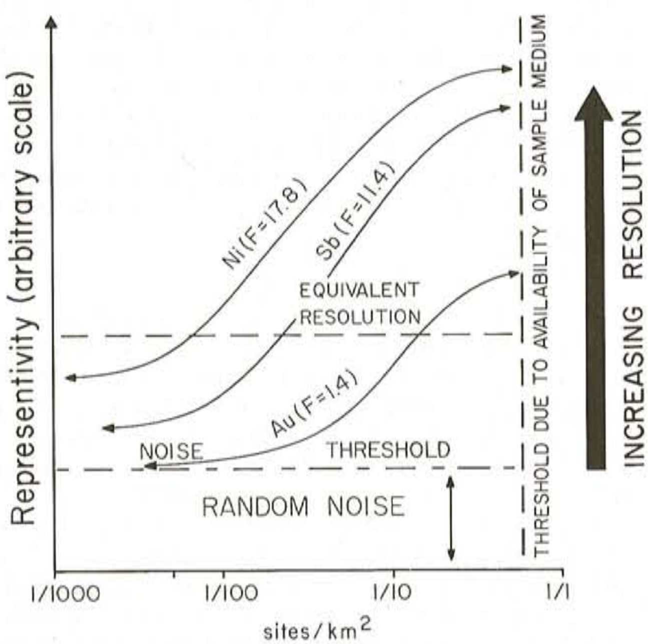

Figure 1. *Schematic depiction of the relationship between sample density and element representivity in lake-sediment data from Newfoundland. Representivity is approximated by the ratio of the total-data variance to the within-site variance (F values).*

A further point, illustrated by Figure 1, is that although an increase in sample-site density will result in an increase in survey resolution, for any particular sample medium there is an optimum range over which this relationship is linear. However, at very high-sample densities further increases in site densities result in smaller and smaller increases in resolution. In the case of lake sediment, sample density is limited by the distribution of lakes, and to increase densities to greater than 1 site per 4 to 5 km², either very small ponds and marshes must be sampled, which commonly yield poor samples with a consequent loss of data quality, or multiple sites must be sampled in the larger lakes, which results in an uneven sample-site distribution. In either case, there is little gain in target resolution. To increase resolution, surveys based on other sample media that are intrinsically capable of providing this higher resolution (e.g., soil) must be employed.

At the other extreme the relationship is less clear, although intuitively it seems likely that meaningful patterns will become indistinguishable from background noise at some very low-sample density. Most successful very low-density surveys employ either special sample media such as overbank stream sediment (Ottesen *et al.*, 1989) or a special sampling technique such as that used in the Geochemical Atlas of Finland (Koljonen *et al.*, 1989).

CONCLUSION

These differences in resolution for the different elements in a survey necessitate a flexible approach for producing images of maximum clarity for each element. Smoothing by filtering should aim for the best signal-to-noise ratio. The portrayal of data as carefully prepared images greatly increases their impact and the amount of useful information conveyed. Although some time and effort must be invested for effective data presentation, the resources needed are minor compared with those expended on sample collection and analysis, and add a great deal to the overall impact of geochemical surveys. The linear features revealed by shaded-relief maps of elements such as Ni not only provide new insight into enigmatic structural features such as the 'Buchan's linear' ('A' in Plate 8), but also reveal others ('B'), which may have important implications for regional geological models and mineral exploration.

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REFERENCES

Chork, C.Y. and Cruikshank, B.I.
1984: Statistical map analysis of regional stream-sediment data from Australia. Journal of Geochemical Exploration, Volume 21, numbers 1-3, pages 405-419.

Chork, C.Y. and Mazzucchelli, R.H.
1989: Spatial filtering of exploration geochemical data using EDA and robust statistics. Journal of Geochemical Exploration, Volume 34, number 3, pages 221-244.

Colman-Sadd, S.P., Hayes, J.P. and Knight, I. (Compilers)
1990: Geology of the Island of Newfoundland. Newfoundland Department of Mines and Energy, Geological Survey Branch, Map 90-1.

Garrett, R.G.
1973: The determination of sampling and analytical errors in exploration geochemistry—a reply. Economic Geology, Volume 68, pages 282-283.

Garrett, R.G. and Goss, T.I.
1980: The appraisal of survey effectiveness in regional geochemical surveys of Canada's Uranium Reconnaissance Program. Mathematical Geology, Volume 12, pages 443-458.

Howarth, R.J.
1983: Statistics and Data Analysis in Geochemical Prospecting; Handbook of Exploration Geochemistry, Elsevier, 437 pages.

Kilfoil, G.J.
1990: DISPLAY: A computer program for the interactive display of files of gridded data on a VGA monitor—program diskette and user's manual, version 1.0. Newfoundland Department of Mines and Energy, Geological Survey Branch, Open File NFLD 2064.

This volume: DISPLAY: An interactive program to create colour images of spatial data on a PC.

Koljonan, T., Gustavsson, N., Novas, P. and Tanskanen, H.
1989: Geochemical Atlas of Finland: preliminary aspects. Journal of Geochemical Exploration, Volume 32, pages 231-242.

Nolan, L.W.
1990: UNISTAT: statistical and graphics package for geochemists. *In* Current Research. Newfoundland Department of Mines and Energy, Geological Survey Branch, Report 90-1, pages 129-130.

Ottesen, R.T., Bogen, J., Bolviken, B. and Volden, T.
1989: Overbank sediment: a representative sample medium for regional geochemical mapping. Journal of Geochemical Exploration, Volume 32, pages 257-278.

Rock, N.M.S.
1987: ROBUST: an interactive FORTRAN-77 package for exploratory data analysis using parametric, robust and nonparametric location and scale estimates, data transformations, normality tests, and outlier assessment. Computers in Geoscience, Volume 13, pages 463-494.

Sinclair, A.J.
1976: Applications of probability graphs in mineral exploration. Association of Exploration Geochemists, Special Volume 4, Rexdale, Ontario, 95 pages.

Teskey, D. and Broome, J.
1984: Computer programs for production of shaded relief and stereo shaded relief maps. *In* Current Research, Part B. Geological Survey of Canada, Paper 84-1B, pages 375-389.