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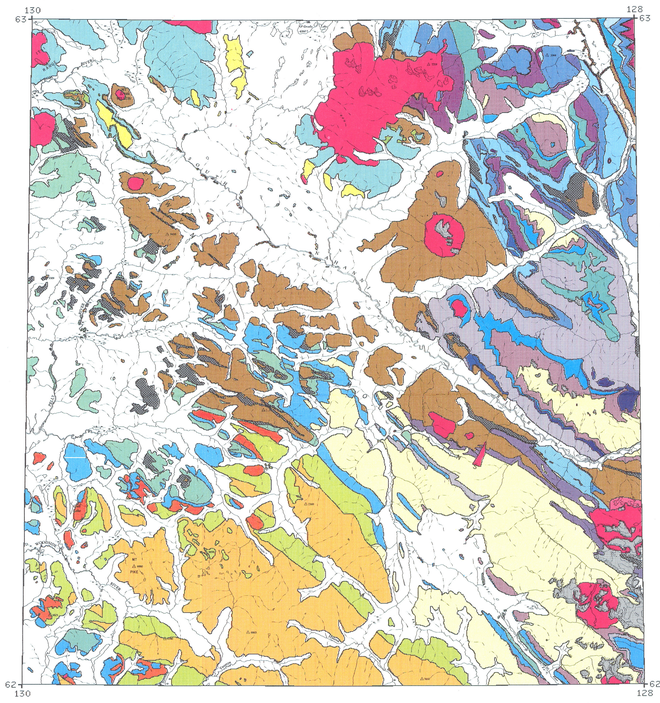

Figure 1. Geological map at 1:500 000 scale of Nahanni River area, NTS 105I, published as Open File 780 by Gordey (1981). From the original uncoloured map (scale 1:125 000) a stable base overlay showing geological contacts only was produced at 1:125 000 scale. This was raster-scanned, thereby digitally recording the presence/absence of contacts only. Subsequent processing involves the creation of a geographic data base, corrected according to registration points, with polygons labelled by sequence number and related to geological map unit in a lookup table. Finally a grid file was created, using a pixel size of 50 m on the ground to be used for colour plotting and for merging with catchment basins.

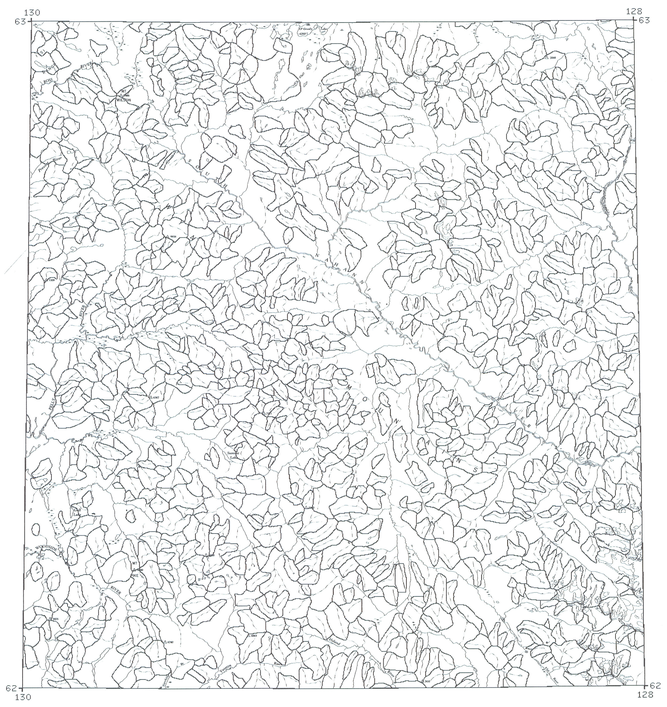

Figure 2. Map showing outlines of catchment basins, digitally plotted at 1:500 000 scale. The drainage has been superimposed photographically. The steps in raster-scanning, with the ultimate product being a grid file with a pixel size of 50 m on the ground, are identical to those for the geological map.

GSC PAPER 85-26
NAHANNI RIVER MAP AREA (105 I)
YUKON AND NORTHWEST TERRITORIES

D.J. Ellwood
G.F. Bonham-Carter
W.D. Goodfellow

Scale 1:500 000 Échelle

Kilometres 12 0 12 24 36 Kilomètres

Universal Transverse Mercator Projection — Projection transverse universelle de Mercator

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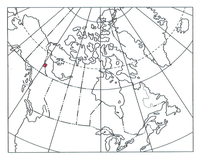

INDEX MAP

Abstract

This paper describes and illustrates the production of digital maps of regional stream geochemical data, analyzed by catchment basin analysis. Advances in computer-graphics technology permit the routine raster-scanning of geological and catchment basin maps. In digital form, the information from these maps, coupled with a geochemical data base, is manipulated to estimate the geochemical background for each element in each catchment basin. After correcting positive anomalies for basin area, maps depicting mineralization ratings are produced in colour (or grey-tones), providing a valuable tool for follow-up exploration.

Résumé

L'étude décrit et illustre la façon de produire des cartes digitales comportant des données géochimiques sur les cours d'eaux à l'échelle régionale. Ces données sont obtenues d'analyses de chaque bassin hydrographique. La technique d'infographie sans cesse en évolution permet maintenant d'effectuer des balayages courants par lignes de trame de cartes géologiques et hydrographiques. L'information numérique présentée sur les cartes et la base de données géochimiques permettent d'évaluer les antécédents géochimiques de tous les éléments de chaque bassin hydrographique. Après correction des anomalies positives relevées à l'égard de chaque région de bassin, il faut préparer des cartes polychromes (ou en dégradé gris) donnant un aperçu de l'importance de la minéralisation de ces régions. Ces cartes constituent un précieux instrument de travail pour l'exécution de nouveaux projets d'exploration.

INTRODUCTION

The maps presented here illustrate a method of correcting for background variations in stream geochemical data, thereby highlighting effects due to mineralization. It is a mathematical method, heavily dependent on computing, yet the basic approach is simple to understand. The geochemical response measured in a stream sediment or water sample is influenced by the bedrock geology, transported surficial materials – particularly glacial deposits–, chemical processes in the surficial environment such as the scavenging of metals by (Fe,Mn) hydroxides, and lastly if present, mineral deposits. If the effects of the factors unrelated to mineralization can be estimated and removed from the survey data, the resulting residuals highlighting mineralization can be further evaluated and follow-up surveys undertaken where appropriate. Here we have been able to remove the effects of geochemically contrasting bedrock lithologies and the dilution effects of large catchment basins; independent effects due to glacial and surficial chemical processes, and mineralization are still contained in the residuals.

The application of this method to data from the Nahanni River area, Yukon and NWT, and to the Cobequid Highlands, Nova Scotia, has been described in Bonham-Carter and Goodfellow (1984, 1985) and in Bonham-Carter et al. (1985b). The purpose of the present paper is to describe the steps in making the various maps involved in catchment basin analysis, and to illustrate these maps in colour.

METHOD

The resources needed to undertake catchment basin analysis are: 1) a computer file containing for each sample accurate co-ordinates defining location, and the analytical results for each geochemical determination; 2) a geological map; and 3) a topographic map showing drainage.

The first step is to plot the stream sample sites on a stable base at the same scale as the topographic map. Sites are checked to make sure they fall on streams, and if editing is required this is done using the original field sheets. It is vital that the sites be plotted digitally, so that subsequent digitally-plotted overlays will be in exact registration.

The boundaries of sample catchment basins are then inked onto a second overlay. Boundaries are identified using topography, the edge of the map, drainage, and sample sites. These boundaries define a polygon for each site which represents all – or if there are other samples upstream, a portion of – the sample catchment basin. This procedure is somewhat subjective, particularly in areas of low relief with widely-spaced contours. A digital terrain map would improve the precision of this process, and could be used with an algorithm for automatically detecting catchment boundaries. After adding registration points at each corner, whose exact geographic co-ordinates are known, and a 'neat' line as boundary, the completed map is digitized on a drum scanner. This digitizing process is described in Bonham-Carter et al. (1985a). The ultimate product is a computer file containing a raster image. Each pixel in the image is labelled according to the polygon in which it occurs. A lookup table which relates polygon number to sample number provides a link to the geochemical data file.

The geological map is digitized in a similar fashion. The geological contacts comprise polygon boundaries. Other geological data, such as faults, are not included. Again, a polygon map, with registration points and 'neat' line, is raster scanned. The final product is a second raster image, with the same pixel size and origin as the sample catchment basin map. A lookup table is created which relates polygon number to mapped unit.

The two raster images, geology and catchment basins, are now digitally merged, so as to produce a table which gives the area of each geological unit in each catchment basin. These data are in turn merged with the geochemical file, so that each sample is described by location, geochemistry, and geological areal composition of its associated catchment basin. If a digital terrain map were available, the average elevation, slope, roughness, and orientation of the catchment basin could also be calculated.

Where sampling has been carried out in such a way that nested basins occur, with large basins containing several smaller basins, a hierarchical network of linked samples results. This is quantified by providing a link number which denotes the number of the next sample downstream, if it exists. From the link numbers, the nested catchment basins upstream of any given sample point can be determined digitally, and the full area of the 'parent' basin is determined by adding the areas of all the upstream 'daughter' basins.

The raster-scanning of the maps shown in this report has been carried out by Canada Lands Inventory, Lands Directorate, Environment Canada, using an Optronics laser scanner. Their software was used to create the raster files at a pre-selected scale and origin. Software written at the Geological Survey of Canada was used to carry out the analysis and produce Applicon colour plots. With data organized in this form, catchment basin maps can be produced at any scale for any of the geochemical elements, or for derived quantities such as linear combinations, residuals, or principal components. The Optronics scanner can also be used in 'playback' mode to produce output in the form of positive transparencies. Four transparencies (black, magenta, cyan and yellow) were created for this publication, registered and used directly for the production of printing plates, thereby avoiding the photomechanical and colour separation process.

Geological background prediction

That part of the geochemical response that is due to differences in average chemical composition between map units, i.e. the background, is estimated using a regression model. Spatial trends within geological units are not modelled. The method has been described by Bonham-Carter and Goodfellow (1984, 1985), and is similar in concept to Rose et al. (1970).

An equation which predicts the content of an element in a stream sample on the basis of the geological composition of the associated catchment basin is derived by multiple linear regression. The regression coefficients, one coefficient for each mapped unit, are estimated by least squares, and are those coefficients which minimize the sum of the squared differences between observed and predicted element contents. The whole sample set is used simultaneously in this operation. Thus, a catchment basin map of predicted element content can be produced, where prediction is based solely on the mapped geology. It has been argued that the 'anomalous' samples should first be removed, as the predicted background is biased upwards by including anomalies. Because of the arbitrary nature of choosing a cutoff, we have preferred to treat the entire sample set, avoiding the cutoff decision. Predicted geological background may thus be biased upwards for some samples, but the rank order of samples is probably relatively unaffected.

Residual element content at each sample site is determined by subtracting the predicted content from observed content. A catchment basin map of residuals may be the last stage of computation, or the residuals may be further transformed by correcting for dilution, i.e. catchment basin size. For areas of mineralization of equal size occurring in two basins of different area, it is clear that dilution is greater in the larger basin. Using a simple relation derived by Hawkes (1976), we have determined 'mineralization ratings' which correct the positive residuals according to basin area. The larger basins will thus yield mineralization ratings with a higher rank order than the regression residuals alone.

In some cases, this correction process may amplify the noise in the system due to analytical error and variance between samples collected at the same site. For elements associated with poor analytical precision and a 'noisy' map of observed values, or for cases where large differences in basin area occur, this dilution correction is not advised.

MATHEMATICAL MODEL

Let X_{ij} be the areal proportion of the i-th catchment basin underlain by the j-th mapped unit. Note that if basins are nested, a large basin may include several smaller basins. Thus any given pixel may contribute to more than one basin.

Let Y_i be the measured (observed) element content of the i-th sample (corresponding to the i-th basin). Then the predicted element content, $\hat{Y}_i$, is assumed to be the sum of the contributions from each mapped unit occurring in the i-th basin. Further, it is assumed that sediment draining from the j-th mapped unit can be represented by an average element content, b_j, and that the contribution from that unit is simply the product of the areal proportion and the average element content. Thus

$$\hat{Y}_i = \sum_{j=1}^{m} b_j X_{ij} \quad \text{for } j = 1, 2, \ldots m \qquad (1)$$

where m is the number of mapped units.

This model thus ignores spatial trends in chemical composition within a given map unit, because b_j is a constant, not a function of map co-ordinates. Furthermore, the basic model makes no allowances for glacial transport, or for chemical and physical processes in the secondary environment. The residuals, $(Y_i - \hat{Y}_i)$, will still contain information related to these factors, plus information due to mineralization.

Equation (1) can be solved by multiple linear regression. The b's are the regression coefficients, and are solved simultaneously for all m rock types by minimizing the sum of squared residuals $\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2$ over all n basins.

The predicted element content, $\hat{Y}_i$, is thus the background for the i-th basin. It suffers from bias, however, in that basins containing mineralization, and basins affected by secondary processes, are included in the background estimation.

Equation (1) can be solved using standard statistical programs for multiple regression. Because the distributions of most elements are positively skewed, and because the variance of the residuals is assumed in regression to be independent of element content, in practice the Y's in equation (1) should be logarithms of element content. This means that the additive model is actually multiplicative, but leads to a good fit to the data for many elements. By taking the antilog of the b's, a value roughly equivalent to a geometric mean element content can be obtained for each geological unit. These values are often difficult to interpret, and Bonham-Carter et al. (1985b) have suggested an alternative method for determining the mean element content of sediment draining from a geological map unit.

In order to correct for dilution, Hawkes (1976) developed the following simple relationship

$$R_i = (Y_i - \hat{Y}_i)\, A_i + \hat{Y}_i \qquad (2)$$

where R_i is a mineralization rating for the i-th sample, A_i is the area of the i-th basin and Y_i and $\hat{Y}_i$ are the observed and background element content as before. Thus the rating is equal to the residual or anomaly multiplied by the area of the basin, plus the background. This contrasts with Yu and Xie (1985) who used an expression for "normalized area productivity", NAP, which in our context here would be defined as

$$NAP = \left(\frac{Y_i - \hat{Y}_i}{\hat{Y}_i}\right) S_i \qquad (3)$$

where S_i is the area of the anomaly.

R_i is a rating which takes into consideration both the area of mineralization and its element content. Thus a catchment basin having a large area of medium grade mineralization might be indistinguishable from a small area of high grade mineralization. The units for R_i are those of element content in a stream as if the positive anomaly were wholly due to a deposit exposed over an area of 1 km². It is assumed that contributions from alluvial river bank material can be neglected, that no feedback between sediment and water occurs, and that erosion is uniform within each catchment basin.

This dilution relation assumes that element content is not logarithmically transformed. Thus for solving equation (2), Y_i and $\hat{Y}_i$ are both in the original units. Ratings are only calculated for positive residuals. Some care should be exercised in using this formula for other data sets, because if very large differences in basin area occur, the errors in Y_i and $\hat{Y}_i$ will be greatly amplified. Thus a very large basin with a weak positive anomaly due only to random noise may give rise to an apparently significant rating.

MAPS

The following maps are shown to illustrate the steps in analysis. Figure 1 is a digitized geological map of the Nahanni River area. Figure 2 shows catchment basins, originally drawn by hand using a topographic base. Figure 3 shows the original zinc in sediment values, plotted in the catchment basins using a percentile scale. The predicted zinc background, calculated using equation (1) is shown in Figure 4. Finally, Figure 5 shows mineralization ratings, after correcting positive residuals for differences in basin area, using equation (2).

SUMMARY

(1) The method removes the geochemical background predicted by mapped geology, and corrects for dilution caused by differences in catchment basin area. The method is suitable for regional geochemical data in well-mapped areas of moderate to strong topographic relief. Background variation due to different glacial geology and geochemical processes acting in the surficial environment are not corrected for, unless they correlate very strongly with the geology, and are still present in the residuals. The method is not suitable in flat-lying areas covered predominantly by transported glacial material since the material is largely exotic and unlikely therefore to represent the underlying geology.

(2) Raster scanning of geological and catchment basin maps provides an accurate and comparatively inexpensive procedure for areal data capture.

(3) Statistical analysis and map production have been carried out with a CDC CYBER 170/730 computer, an Applicon ink jet plotter, and an Optronics laser scanner used in 'playback' mode. Catchment basin maps, at a chosen scale, can be produced showing any of the measured or calculated values from stream sample sites.

(4) The method was successful in improving prediction of known Pb-Zn deposits in the Nahanni River area (Bonham-Carter and Goodfellow, 1984), and has also been applied, with some additions, to stream data from the Cobequid Highlands, Nova Scotia (Bonham-Carter et al., 1985b).

ACKNOWLEDGMENTS

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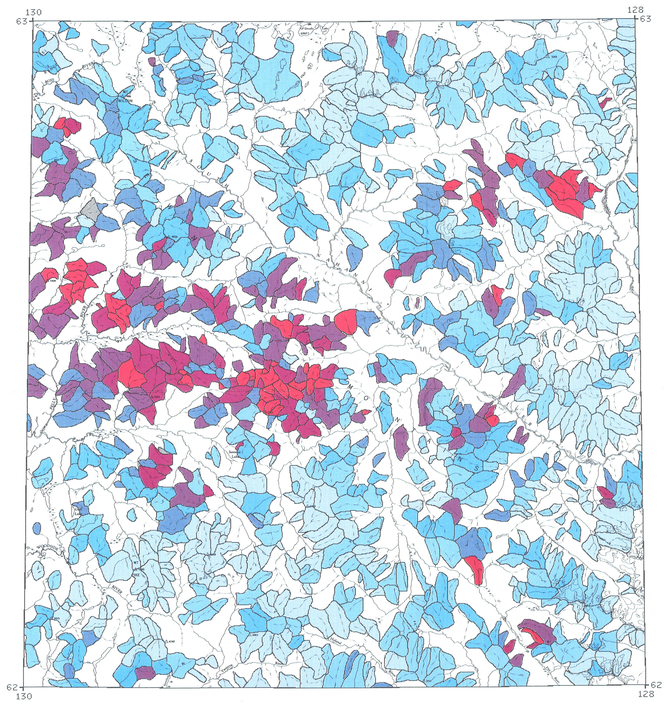

Figure 3. Zinc in stream sediment, using observed data values from Goodfellow (1982) before statistical analysis. Each catchment basin is coloured according to a percentile scale. The polygon associated with each basin is related to a stream sample number in a lookup table. Any characteristics of a stream sample (chemical composition, geological composition of associated basin) can thus be plotted using a colour scale.

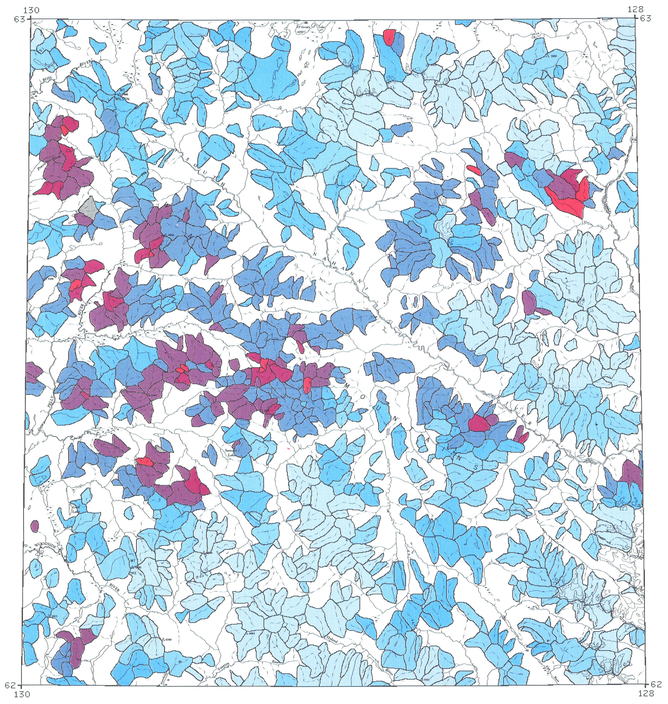

Figure 4. Background zinc in stream sediment predicted from the geology of catchment basins. These values are those obtained from a regression equation, minimizing the sums of squares of the residuals. The independent variables are the areal proportions of each mapped unit in each basin. The regression coefficients reflect the geological background of each mapped unit for zinc. Notice that in general the major trends are predicted rather well. The proportion of the total variance of zinc explained by the geology is 58% for this case.

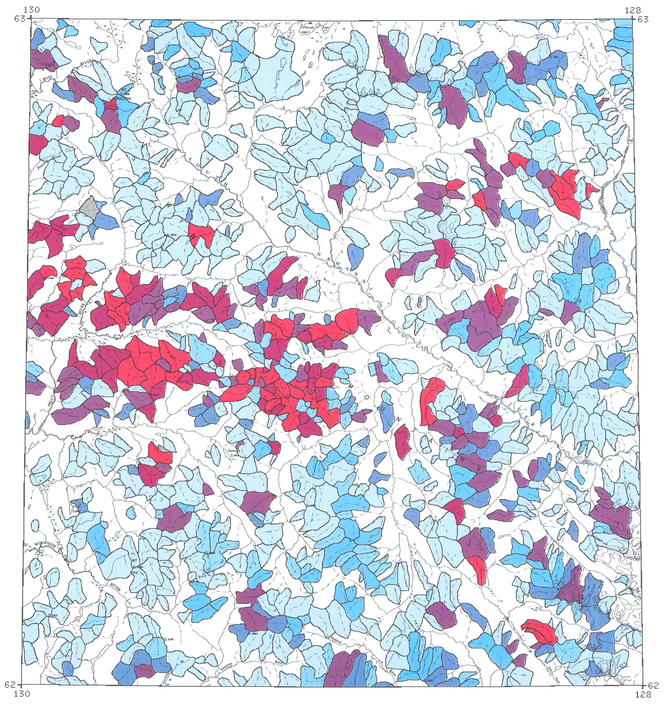

Figure 5. Mineralization ratings for zinc in stream sediment. Positive residuals are corrected for dilution using basin area yielding mineralization ratings, which are re-cast as percentiles. Negative residuals are not corrected, and are simply shown as below the 50th percentile. Hawkes' (1976) dilution formula has been used, which assumes that the positive residuals are entirely due to a 1 km² area of exposed mineralization in the catchment basin. The mineralization rating value is the element content of sediment in surface water draining this hypothetical unit area of mineralization. In reality, of course, the mineralization is variable in size, possibly large and low grade, or small and high grade, but this method at least standardizes catchment basins for the effect of dilution. Basins with the highest mineralization ratings are of most interest for exploration follow-up.

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AN AUTOMATED PROCEDURE FOR CATCHMENT BASIN ANALYSIS OF STREAM GEOCHEMICAL DATA

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